Categorisation and chemical composition of Cape hake- (*Merluccius* ssp.) waste

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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Abstract

Cape hake (*Merluccius capensis* and *M. paradoxus*) is commercially the most important trawl-caught fish off the South African, coastline and due to current intensive fish processing procedures Cape hake contributes the most to the total fish-waste production. Besides its commercial importance fish is also regarded as one of the single most important consumable natural resources, either in the raw or frozen form. Most of South Africa's commercially trawled demersal fish has already been partially cleaned (i.e. headed and gutted) before landing with non-marketable bycatch and hake-waste normally disposed of as discards, resulting in a waste of a potential protein source.

This study was thus aimed at fulfilling several objectives namely: observing the current large-scale commercial Cape hake harvesting procedure; constructing prediction models for several morphological parameters (whole hake mass, headed & gutted hake mass, hake head mass, hake head length, hake head breadth and hake head height) of Cape hake (*Merluccius* ssp.), using whole hake length as the independent variable; and determining the chemical composition (moisture, protein, fat, ash, macro and trace elements) of several hake head sections (clean head, neck flesh, tongue, tongue cartilage, jaw, gills, heart, intestines, gut, kidney, kidney & kidney bone and gut & gall); determining the effect that storage has on the fatty acid profile of both the clean head and neck flesh sections. The results obtained would supply necessary data required for techno-economic investigations in the use of hake heads.

For each of the six prediction models constructed, there was an increase in the variance of the data points of categories 3 (64-80 cm) and 4 (>80 cm) as opposed to categories 1 (30-46 cm) and 2 (47-63 cm). This could be attributed to a smaller sample set for both categories 3 and 4 or due to an expected increase in the variance when investigating larger biological samples. There was also a clustering of data in the three areas for each prediction model namely, within category 1 and across categories 2 and 3 and 3 and 4. This emphasised the latitudinal stratification of the Cape hake population by age, hence their stratification by size. The prediction models constructed for both boat trips 2 and 3 differed significantly ($p<0.01$) from that

of boat trip 1, with the exception of the hake head length (cm) prediction model. The constructed prediction models, for each of the three respective boat trips, showed good predictive abilities as was indicated by the low Mean Square Error (MSE) values for the test sets, and high Pearson's correlation coefficient (r) values. These prediction models can be used in the fishing industry with confidence for Cape hake within the time frame each respective boat trip was carried out.

The neck flesh could be regarded as the most important concerning chemical composition whereas the jaw could be seen as the most important when one considers mineral content. This therefore means that the jaw section, once appropriately processed is a potential Ca, Na and Fe source for supplementing diets of people suffering from a Ca, Na or Fe deficient diet. With regard to chemical status the neck flesh section is seen as a good potential source of both protein and fat, which could be attributed to the fact that hake muscle constitutes a major portion of this section. This section could thus be used to supplement the protein and fat of an existing food product, which is protein and fat deficient for people suffering from a protein and fat deficient diet.

Similarly, a market could be created for the production of an economical food product with the neck flesh section being the main ingredient. Once this have been accomplished, fishing vessels may be persuaded to retain their Cape hake fish-waste for further processing due to the value of the prepared food products and thereby maintain profitability while abiding to governmental law.

In conclusion non-government scientists should have more input in the decision-making process concerning matters affecting South Africa's marine biodiversity in order for future key policy and legislation drafts to be effective. Improvement of current fish preservation techniques and the known chemical composition of currently discarded material will result in informed decisions of future matters concerning its disposal.

Uittreksel

Kaapse stokvis (*Merluccius capensis* en *M. paradoxus*) is kommersieel Suid-Afrika se belangrikste vis spesie. Aangesien die Suid-Afrikaanse visprosesseringsbedryf baie intensief is, dra die Kaapse stokvis verwerkingsindustrie die grootste gedeelte by tot die totale visafval produksie. Die meeste van Suid-Afrika se visvangste word gedeeltelik skoongemaak voor landing terwyl nie-kommersiële byvangste en visafval gewoonlik oorboord gegooi word tydens die vangproses. Dit lei tot die vermorsing van 'n potensïele proteïen bron.

Hierdie studie was dus gemik om: die huidige grootskaalse kommersiële Kaapse stokvis visvangsproses waar te neem; voorspellingsmodelle vir verskeie morfologiese parameters (heel vis massa, vis massa sonder kop en binnedele, stokvis kop massa, stokvis kop lengte, stokvis kop breedte en stokvis kop hoogte) vir Kaapse stokvis (*Merluccius* ssp.) te ontwikkel deur die hele lengte van die vis te gebruik as die onafhanklike veranderlike; die chemiese samestelling (vog, proteïen, vet, as, makro en spoor elemente) van verskillende dele van die viskop (skoonkop, nekweefsel, tong, tong kraakbeen, kaak, kiewe, hart, ingewand, derm, nier, nier & nierbeen en derm & gal); sowel as die effek van opberging op die vetsuurprofiel van beide die skoonkop en nekweefsel dele van die Kaapse stokvis kop. Hierdie resultate sal dan gebruik word vir die tegnies-ekonomies ondersoek in die gebruik van Kaapse stokvis koppe.

Vir elk van die ses voorspellingsmodelle ontwikkel, was daar 'n vermeerdering in die variansie van die datapunte vir kategorieë 3 (64-80 cm) en 4 (>80 cm) teenoor kategorieë 1 (30-46 cm) en 2 (47-63 cm). Dit kan moontlik wees as gevolg van die kleiner monster trekking vir beide kategorieë 3 en 4 of as gevolg van verwagte toename in variansie wanneer groter biologiese monsters ondersoek word. Daar was ook 'n groepering van data in drie plekke vir elke voorspellingsmodel naamlik; binne in kategorieë 1 en oor kategorieë 2 en 3 en 3 en 4. Dit beklemtoon die geografiese breedte van die Kaapse stokvis populasie op grond van ouderdom, en dus die geografiese breedte op grond van grootte. Die voorspellingsmodelle ontwikkel vir beide die tweede en derde bootvangs het betekenisvol verskil ($p<0.01$) van die eerste bootvangs, behalwe die vir die stokvis kop lengte (cm) voorspellingsmodel. Die voorspellingsmodelle vir elk van die bootvangste het goeie voorspellingsvermoë getoon wat bewys is deur die lae Gemiddelde Kwadraat Fout waardes vir toetsgroepe en hoë Pearson's korrelasie koeffisiënt (r) waardes. Hierdie voorspellingsmodelle wat ontwikkel is, kan dus met vertroue in die Kaapse stokvis visvangsbedryf gebruik word mits dit ooreenstem met die periode waarin elke bootvangs uitgevoer was.

Die nekweefsel gedeelte is die mees belangrikste met betrekking tot chemiese samestelling en die kaak die belangrikste in terme van minerale samestelling van die verskeie viskop dele. Die kaak is dus, as dit voldoende geprosesseer word, 'n goeie potensïele bron van Ca, Na en Fe en kan dus gebruik word om die dieet van mense wat 'n gebrek het aan hierdie minerale aan te vul. Met betrekking tot die chemiese samestelling van die nekweefsel gedeelte kan dit beskou word as 'n goeie potensiële bron van beide proteïen en vet, wat toegeskryf kan word aan die feit dat spierweefsel 'n groot deel uitmaak van hierdie viskop gedeelte. Hierdie viskop gedeelte sal dus uitstekend wees om die proteïen- en vetinhoud van 'n voedselproduk wat van nature 'n lae proteïen- en vetinhoud het te verhoog en hierdie produk sou dan geteiken word op daardie gedeelte van die gemeenskap wat 'n proteïen en vet tekort in hul dieet het.

As dit eers alles in plek is, dan sal die visvangs bedryf hul Kaapse stokvis afval behou vir verdere prosessering deurdat dit gebruik word om die voedingsinhoud van bestaande voedsel soorte sal verbeter en terselfdertyd sal hulle aan wetgewing voldoen. Gevolglik sal nie-regerings navorsers meer betrokke moet wees by die besluitnemingsproses met betrekking tot sake wat die Suid-Afrikaanse mariene lewe affekteer en wat toekomstige wetgewing meer effektief sal maak. Die verbetering van huidige vis preserveringstegnieke gepaardgaande met die kennis van die chemiese samestelling van die Kaapse stokvis koppe sal lei na beter toekomstige besluite oor die afset daarvan.

Contents

The language and style used in this thesis are in accordance with the requirements of the *International Journal of Food Science and Technology*. This dissertation represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, therefore, been unavoidable.

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Chapter 1

Introduction

Fish-waste generated during trawling has generally been considered a logistic problem rather than value. According to the statutes of the Republic of South Africa Fisheries, the Sea Fishery Act. No. 98 (1990), "Any person who dumps or allows to enter or permits to be dumped or discharged in the sea anything which is or may be injurious to fish, fish food or aquatic plants, or which may disturb or change the ecological balance in any area of the sea, or which may detrimentally affect the marketability of fish or aquatic plants, or which may hinder the catching of fish, shall be guilty of an offence and liable of conviction to a fine not exceeding R50 000 or to imprisonment for a period not exceeding six years to both such a fine and such imprisonment" (Government Gazette No. 12621). Due to the nature of the fishing industry this illegal activity, however, still continues. This can partly be attributed to the lack of infrastructure to effectively enforce legislation in this industry. The priority of the fishing industry, and for that matter any other industry, is to ensure that its income exceeds its expenses thereby making a profit.

The local Cape hake (*Merluccius* ssp.) trawl fishing industry accounted for 66% of the mass of 17 important species of trawl fish landed from 1955 - 1968 (Botha, 1970) with an annual average of 143 000 tonnes landed during 1986 -1992 (Punt, 1994). In 1995 the demersal trawl fishery sector contributed more revenue in terms of wholesale value (R805 million) than any of the other fishing sectors (Booth & Hecht, 2000). It is therefore of no surprise that Cape hake is commercially the most important trawl-caught fish off the South African (O'Toole, 1978) and Namibian coastlines (Hamukuaya, 1994) with an annual average of 148 552 and 142 130 tonnes caught during 1996 and 1999, respectively (Fishing Industry Handbook, 2002).

The current fish processing industry is largely based on intensive processing, resulting in the accumulation of large amounts of waste consisting of skin and connective tissue, which is rich in collagen (Montero & Borderías, 1991;

Montero *et al.*, 1999). "Discarded catch" is defined by the FAO (Food and Agriculture Organisation of the United Nations) as "That portion of the catch returned to the sea (or otherwise thrown away) as a result of economic, legal or personal considerations - deemed to have no or even a negative value to the catcher" (Clucas, 1996). For the purpose of this study "fish-waste" will refer to hake heads (*Merluccius* ssp.), which are thrown overboard the trawler as a result of economic considerations.

At present fish-waste is considered of no monetary value and is not retained for further processing. A small volume of fish-waste is used to manufacture fishmeal (onboard vessels with the appropriate equipment), a product that yields very little profit (Montero & Borderías, 1990). The most economical way for fishing companies to discard fish-waste is to throw it overboard. The shipping vessels consequently only store prime portions of their daily catch onboard the vessel to optimise their allocated storage space, and ensure optimum profits. The only logical solution in eliminating on-going illegal activities and optimising the value of the whole catch would be to find a way to increase the value of the fish-waste. Enforcement of more stringent legislation is highly unlikely to be carried out efficiently.

Although fish-waste contains favourable characteristics it is senselessly discarded and only the prime portions of the fish are used for human consumption. The favourable characteristics of fish-waste, could be appealing to certain potential markets if value could be added to it. Fish-waste, which is collagen-rich, is high in nutritional and functional value (Montero & Borderías, 1990). Collagenous material can be used as a gelifying agent and has major applications in the food industry. Collagen isolated from fish-waste (i.e. skin, bone and fins) from several fish species including Japanese sea-bass (*Lateolabrax japonicus*) consisted of 51.4% skin collagen, 40.7% bone collagen, 5.2% acid-soluble and 36.4% acid-insoluble fin collagen. This substantiates the fact that fish-waste materials can be regarded as a potential collagen supplement (Nagai & Suzuki, 2000).

To date fish-waste has been directed mainly to animal feed though some examples of use for human consumption products have been investigated. The Fishing Industry Research Institute (FIRI), now incorporated into the Bio/Chemtek Business Unit of the CSIR, has been involved with fish-waste utilisation and has developed products from shark and ribbonfish, i.e. sausage, biltong, patés as well as various products from various sections of hake offal. Omega-3 and omega-6 fatty acids have been extracted from hake heads, leather produced from fish skin and high-protein biscuits made from hake head pulp (Karaan *et al.*, 1998). A stable animal feed ingredient, which can improve organoleptic quality and nutritional composition of the respective animal feed, had been manufactured from pilchard (*Sardina pilchardus*) waste (viscera, heads and tails) with the use of pure yeast cultures (*Saccharomyces* sp.) and lactic acid bacteria (*Lactobacillus plantarum*) (Faid *et al.*, 1997). Hake (*Merluccius merluccius*, L) contains significant amounts of calcium (Ca) and phosphorus (P) (Martínez-Valverde *et al.*, 2000).

Fish-waste is considered as unfavourable for human consumption, as it is visibly unpleasant. The obvious ways to overcome this problem is by processing the fish-waste and by incorporating it into an existing food product or by developing a totally new and acceptable food product with its sole ingredient being fish-waste. Once this has been accomplished, fishing vessels may be persuaded to retain their fish-waste for further processing due to the value of the prepared food products and thereby maintain profitability while abiding by governmental law. Readily affordable, nutritional food products can then be made available to South Africa's communities, either directly or through government aided feeding programmes.

Utilisation and/or reduction of bycatch (i.e. non-target species - discarded catch plus incidental catch) are becoming an important factor to consider within the trawl fisheries (Broadhurst & Kennelley, 1994; Clucas, 1996; Booth *et al.*, 1999). Bycatch can be utilised by improving fishing gear to selectively exploit these resources (Booth *et al.*, 1999) as almost all bycatch species die after capture (Broadhurst & Kennelley, 1994). If facilities to process these by-catch resources are unavailable then methods to reduce bycatch should be implemented such as exclusion devices (Broadhurst & Kennelley, 1994). Currently all trawl bycatch are under-utilised, therefore bycatch needs to be assessed carefully (Booth & Buxton, 1997) and research needs to be conducted on developing alternative bycatch products and establishing suitable potential markets (Booth & Hecht, 2000). In addition, the trend towards aquaculture to supply the world need for fish due to dwindling ocean stocks, will result in large volumes of fish-waste being produced on land with no easy means of disposal.

The objectives of this study were to:

- Use whole hake length (cm) as the independent variable to construct prediction models which will be used to predict morphological parameters: whole hake mass, headed & gutted hake mass, hake head mass, hake head length, hake head breadth and hake head height;
- Determine the chemical composition of Cape hake-waste (*Merluccius* spp.);
- Determine the chemical composition differences between the associated hake head sections (i.e. clean head, neck flesh, tongue, tongue cartilage, jaw, gills, heart, kidney, gut and intestines); and
- Evaluate the effect of storage on the fatty acid profile in the clean head and neck flesh sections.

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Chapter 2

Literature review

A. Introduction

Fish is regarded as one of the single most important consumable natural resources, either in the raw or frozen form, due to its high protein content and because it is rich in long-chain highly unsaturated fatty acids (Méndez *et al.*, 1996; Vareltzis *et al.*, 1997). Locally, Cape hake (*Merluccius capensis* & *M. paradoxus*) is commercially the most important trawl-caught fish off the South African (O'Toole, 1978) and Namibian coastlines (Hamukuaya, 1994) with an annual average of 148 552 and 142 130 tonnes caught during 1996 and 1999, respectively off the South African coastline (Fishing Industry Handbook, 2002). Cape hake was originally thought to have been made up from a single species (Payne, 1946), which is not surprising since the two species of Cape hake which occurs off the South African coastline namely, the shallow-water (*Merluccius capensis*) and deep-water (*Merluccius paradoxus*) Cape hake (Payne, 1946; Botha, 1974; Stewart et *al.*, 1988; Becker & Kirby, 1988; Pillar & Wilkinson, 1995; Osborne *et al.*, 1999;), are similar in appearance (Botha, 1974; Cohen *et al.*, 1990a and 1990b; Gordoa *et al.*, 1995). Even though these two species are similar in appearance there are morphological differences between them (Cohen *et al.*, 1990a and 1990b). Both species belong to the same class, order and family namely; Actinopterygii (i.e. ray-finned fishes), Gadiformes (i.e. cods) and Merlucciidae, respectively (Cohen *et al.*, 1990a and 1990b).

Cape hake in general do not have many natural predators. The main predators of juvenile hake are two dolphin species, the common dolphin (*Delphinus delphis)* and the dusky dolphin *(Lagenorhyncus obscurus)* (Smale *et al.*, 1994) as well as the Cape fur seal (*Arctocephalus pusillus pusillus)* (Pillar & Wilkinson, 1995). *M. capensis* contributes *ca.* 5-30% to the Cape fur seal's total diet whereas *M. paradoxus* contributes *ca.* 0-30% to their total diet (Punt *et al.*, 1995). Although both species spawn throughout the year (Jones & Van Eck, 1967), the main spawning season usually occurs during spring extending from September to December/January (Payne, 1946; Botha, 1974; O'Toole, 1978; Hamukuaya, 1994; Payne & Punt, 1995).

B. Morphological aspects

The morphological differences between shallow-water (*M. capensis*) and deep-water (*M. paradoxus*) Cape hake include differences in total dorsal and anal soft-ray counts (Cohen *et al.*, 1990a and 1990b), vertebrae count (Van Eck, 1969; Botha, 1971, 1974), otolith (i.e. ear bone) structure and gill-raker pigmentation (Van Eck, 1969; Botha, 1971). The otolith structure of *M. capensis* is flat and pear-shaped whereas that of *M. paradoxus* has a smaller bean-shaped structure (Botha, 1974). It is evident that these two species of Cape hake are visually indistinguishable, hence catches off the South African coastline are simply referred to as *Merluccius* sp. (O'Toole, 1978; Hamukuaya, 1994).

M. capensis occurs approximately between depths of 50-1000 metres whereas *M. paradoxus* occurs approximately between 150-1000 metres (Van Eck, 1969; Stewart *et al.*, 1988; Becker & Kirby, 1988; Cohen *et al.*, 1990a and 1990b; Pillar & Wilkinson, 1995; Osborne *et al.*, 1999). There is an overlap in environmental distribution between these two species at depths between approximately 150-500 metres (Payne, 1946; Van Eck, 1969; Botha, 1974; Becker & Kirby, 1988; Gordoa *et al.*, 1995; Osborne *et al.*, 1999). Due to this a certain degree of hybridisation (<5%) between the two Cape hake species occurs (Botha, 1974). Catches of *M. capensis* almost exclusively dominates off the Namibian coastline, but catch frequency of *M. paradoxus* increases gradually southwards towards the Cape coastline where it eventually becomes the dominant species (O'Toole, 1978). Both species occur in a bathydemersal environment (Cohen *et al.*, 1990a and 1990b).

Trawled *M. capensis* always has a heavier individual mass than that of *M. paradoxus* and this could be attributed to the fact that the larger *M. capensis* environment overlaps with that of the smaller *M. paradoxus* (Huse *et al.*, 1998), which feeds on pelagic prey therefore residing in a pelagic environment (Botha, 1974; Huse *et al.*, 1998).

Females of both species tend to mature faster than their male counterparts with 50% maturity being reached at 470-480 mm and 360-380 mm (*ca.* 4.8 and

3.8 years, respectively), respectively (Botha, 1986a). Although Punt & Leslie (1991) disagree on the latter point, they do agree that females grow faster than their male counterparts, which is also the case for *M. productus* (Dark, 1975). The females of both species dominate the sex ratios by 1.5:1 for *M. capensis* and 1.7:1 for *M. paradoxus* (Botha, 1986a). The instantaneous natural mortality for males is higher than for females (Botha, 1986a; Payne & Punt, 1995). The natural mortality rates for *M. paradoxus* (39%) is higher than for *M. capensis* (34%) at 50% maturity (*ca.* 4 years) (Assorov & Shcherbitch, 1979).

C. Movement and feeding

The shallow-water *M. capensis* dominates off the Namibian coastline while the deep-water *M. paradoxus* occurs off the South African west (Payne & Punt, 1995) and south-west (Fishing Industry Handbook, 2002) coast. Generally Cape hake exhibits extensive diurnal (day & night) vertical movement, lying on the ocean floor during the day and moving into midwaters at sunset (Payne, 1946; Jones & Van Eck, 1967; Botha, 1973; Botha, 1974; Hamukuaya, 1994; Huse *et al.*, 1998). Silver hake (*M. bilinearis*) also resides on the ocean floor during the day and off the bottom at night, which substantiates their dusk and dawn off-bottom peaks and a low concentration experienced around noon (Bowman & Bowman, 1980). It is therefore an unwritten rule in the hake fishing industry that Cape hake is to be deep sea trawled during the day while the majority of the hake shoals reside close to the ocean floor (Botha, 1974).

Cape hake spawn more than once a season, which could possibly explain their marked diurnal migration at night (Payne & Punt, 1995). During abnormally warm summers hake concentrate closer to the ocean floor, where the water temperature is lower, thereby increasing their availability to bottom trawls (Gordoa *et al.*, 1995). This is in agreement with Pillar & Barange (1997) who observed that larger Cape hake (*M. capensis* and *M. paradoxus*) were caught in summer, which they attributed to the inshore migration of hake stocks. This in turn explained the increased hake-on-hake predation in summer, due to the increased overlap in distribution between the smaller and larger hake (Pillar & Barange, 1997).

Cape hake's preference for specific environmental conditions is regarded as a contributing factor to their seasonal diurnal migration (Pillar & Barange, 1997). The diurnal feeding pattern of *M. capensis* is dependent on the size of the hake with small hake exhibiting a pronounced feeding peak at night and a smaller peak in the morning; medium-size hake feeding during the day whereas large hake did not show any clear diurnal feeding pattern, although a small feeding peak could be observed at night (Preński, 1980). Juvenile *M. capensis* migrated vertically into subsurface layers at night, feeding mainly on anchovy (*Engraulis capensis*) whereas the larger hake remained near the ocean floor, not migrating extensively into midwater. This was attributed to the increasing degree of cannibalism where demersal prey became increasingly important in the diet of the larger hake (Pillar & Barange, 1993, 1995, 1997).

Further investigation revealed that a variable proportion of the hake population would remain close to the ocean floor on any given night, which were attributed to the hake's (*M. capensis*) asynchronous feeding behaviour and slow gut evacuation time (>1 day) (Pillar & Barange, 1995).

Table 1 summarises the diet of the *Merluccius* ssp. It is clear that *M. capensis* are opportunistic predators (Payne *et al.*, 1987; Pillar & Barange, 1995, 1997; Pillar & Wilkinson, 1995; Punt *et al.*, 1992), which prey heavily on fish as they become older. Feeding preference of *M. capensis* changes in relation to local availability and abundance (Pillar & Barange, 1995, 1997). Cape hake diet becomes mainly piscivorous with age (Payne *et al.*, 1987; Punt, 1992), with that of *M. capensis* being more so than that of *M. paradoxus* (Payne *et al.*, 1987). Demersal fish contributes a greater proportion to the diet of *M. capensis* than to that of *M. paradoxus* (Payne *et al.*, 1987). In addition to the fact that both Cape hake species are cannibalistic, *M. capensis* prey on *M. paradoxus* and not vice versa (Punt & Leslie, 1995). This could be attributed to their spatial overlap where *M. capensis* is normally larger than *M. paradoxus* (Punt *et al.*, 1992).

Table: 1 The diet of *Merluccius* ssp.

Species	Diet	Reference
Juvenile *M. capensis*	*M.* ssp., Gobiidae, Myctophidae, Euphausiacea, Stomatopoda, Macrura, Anomura, Cephalopoda, *C. decapoda* and *C. octopoda*	Preński (1980)
	small copepods	Pillar & Barange (1995)
	anchovy	Pillar & Wilkinson (1995)
Large *M. capensis*	shoaling prawns (*Funchalia. woodwardi*) and stomatopods (*Pterygosquilla armata capensis*)	Payne *et al.* (1987)
	horse mackerel and hake	Payne *et al.* (1987); Punt *et al.* (1992); Pillar & Barange (1995, 1997); Pillar & Wilkinson (1995)
	Etrumeus whiteheadi and *Engraulis capensis*	Punt *et al.* (1992)
	small *M. capensis* (20-40 cm total length), *Todarodes angolensis*, *Cynoglossus capensis*, *Trachurus capensis*, *Lepidopus caudatus*, *Coelorhynchus fasciatus* and *Etrumeus whiteheadi*	MacPherson & Gordoa (1994)
	euphausiids, meso- and pelagic fish, and demersal fish	Pillar & Barange (1995)
	Etrumeus whiteheadi and *Trachurus trachurus capensis*	Punt & Leslie (1995)
	fish (92%), crustaceans (5%) and cephalopods (pelagic fish (51%), anchovy (33%), round herring and pilchard (11%), horse mackerel (24%) and demersal fish (17%)) (3%)	Pillar & Wilkinson (1995)
Juvenile *M. paradoxus*	euphausiids and mesopelagic fish	Payne (1946); Pillar & Barange (1997); Huse *et al.* (1998)
Large *M. paradoxus*	euphausiids (*Euphausia lucens*, *Nyctiphanes capensis*) and amphipods (*Themisto gaudichaudi*)	Payne *et al.* (1987)
	lightfish (*Maurolicus muelleri*), myctophids (predominantly *Lampanyctodes hectoris*) and cephalopods	Punt *et al.* (1992); Punt & Leslie (1995)
Cape hake	demersal fish	Payne *et al.* (1987); Punt *et al.* (1992)
	small lantern fish, prawns, squid, pelagic goby, horse mackerel and jacopever	Botha (1974); Hamukuaya (1994); Huse *et al.* (1998)
	small crustaceans, fish and cephalopods	Roel & MacPherson (1988)
	shoaling prawns (*Funchalia. woodwardi*) and stomatopods (*Pterygosquilla armata capensis*)	Payne & Punt (1995)
Juvenile Cape hake	lantern fish (*Myctophidae*), small hake, small crustacea and rattails (*Coryphaenoididae*)	Jones & Van Eck (1967)
	euphausiids	Huse *et al.* (1998)
Large Cape hake	small hake, massbanker (*Trachurus trachurus*) and rattails	Jones & Van Eck (1967)
	fish	Huse *et al.* (1998)
***M. bilinearis* (Silver hake)**	*Crangon septemspinosa*, *Dichelopandalus leptocerus* and *Monoculodes intermedius*	Bowman & Bowman (1980)

Juvenile *M. capensis* are regarded as visual predators, pursuing prey items that appear the largest (Pillar & Barange, 1993). Consequently, adult *M. capensis* become progressively more piscivorous in their feeding habit (Pillar & Barange, 1993). Cannibalism is more prominent in *M. capensis* on the south coast than on the west coast of South Africa (Pillar & Wilkinson, 1995), where interspecific predation on *M. paradoxus* is common. There is no distinctive daily diurnal feeding rhythm in both Cape hake species with only some evidence in both species of evening predation dominating (Huse *et al.*, 1998). Payne (1946), however, disagreed and suggested that their diurnal vertical migration could be an instinctive behavioural reaction to where their food is even though they do not need to feed. Besides the fact that the importance of fish in the diet of both Cape hake species increases with size their feeding intensity decreases during the spawning season (Roel & MacPherson, 1988).

For both Cape hake species, especially *M. paradoxus*, euphausiids were eaten more frequently in summer and mesopelagic fish were more of dietary importance in winter (Pillar & Barange, 1997). Cape hake therefore have preference for different prey items with the daily ration for shallow-water *M. capensis* estimated between 1.1 and 4.4% of its body mass and that of deep-water *M. paradoxus* between 0.7 and 4.1% of its body mass (Punt & Leslie, 1995).

The main constituents of the diet of both Cape hake species are small crustaceans, fish and cephalopods, the relative importance of each item varying both geographically and seasonally (Roel & MacPherson, 1988). It is clear that the diet of *M. capensis* is more diverse than that of *M. paradoxus* (Punt & Leslie, 1995) and therefore the prey of *M. capensis* is classified into major food groups with fish (64%), especially mesopelagic fish (50%) being dominant, the latter is also the most frequently occurring prey item in the stomachs of *M. paradoxus*, followed by crustaceans (35%), consisting mostly of euphausiids (25%) and amphipods (8%) (Pillar & Barange, 1997). Crustaceans were consumed relatively infrequently (7%) by *M. capensis* and fish prey occurred in 92% of the stomachs (demersal, 59%; pelagic fish, 23% and mesopelagic fish, 10%). The two major prey taxa of *M. paradoxus*, euphausiids and mesopelagic fish, changed inversely with respect to season with the former being eaten more frequently in summer and mesopelagic fish more in winter.

Hake-on-hake predation is not an uncommon phenomenon since larger *M. capensis* (>60 cm) prey on smaller *M. paradoxus* to a substantial extent where the latter comprises between 25 and 70% of the formers total diet (Ware, 1992; Pillar & Barange, 1997). Large *M. capensis* showed a high mean incidence of cannibalism (86.7%) with a calculated predation rate of one prey item every 4.2-5.5 days (73 prey items annually), which is not influenced by the density of the prey (MacPherson & Gordoa, 1994). The general trend as both hake species get older is to move offshore and therefore the adults are found deeper than their juveniles (Payne & Punt, 1995). Since smaller *M. paradoxus* co-exist with larger *M. capensis* (Botha, 1973; Payne & Punt, 1995) the possibility of interspecific predation of hake taking place is great (Payne & Punt, 1995). Consequently, smaller hake constitute an important component of the diet of larger hake of both Cape hake species, hake constituting up to 50% of the diet of some age classes (Punt & Leslie, 1995). Gordoa *et al.* (1995) investigated juvenile *M. capensis* and reported that with increasing hake length the occurrence of other species decrease while cannibalism increased which is in agreement with findings by both Preński (1980) and Andronov (1987). Hake-on-hake predation cannot always be regarded as true cannibalism, since two species are involved (Payne, 1946). Predation of hake-on-hake in only *M. paradoxus* should thus be classified as true cannibalism with that in *M. capensis* as interspecific predation (Payne *et al.*, 1987).

Large *M. capensis* often co-habit with small *M. paradoxus* which they prey on whereas large *M. paradoxus* are found in areas where small hake are absent therefore true cannibalism of *M. paradoxus* is less common (Payne, 1946). Similarly, small *M. capensis* are less frequently cannibalised than small *M. paradoxus* since they usually reside in shallower water than the adults (Payne, 1946). Both juvenile *M. capensis* (intraspecific predation) and large *M. paradoxus* (interspecific predation) constitutes a large fraction towards the diet of large *M. capensis* (Punt & Leslie, 1995). These findings are in agreement with that of Payne *et al.* (1987) who reported that the occurrence of hake as a prey item indicated that the ratio of *M. paradoxus* to *M. capensis* in the diet was 100:0 for *M. paradoxus* and 74:26 for *M. capensis*.

D. Spawning

Cape hake spawning can be described as a double wave, firstly in November/December by both species concerned and secondly in February/March which is mainly dominated by the *M. paradoxus* species (Botha, 1986a). Due to the fact that Cape hake spawns throughout the year they are referred to as serial spawners. Serial spawners usually possess indeterminate fecundity i.e., the annual fecundity (the total number of eggs spawned by a female per year) is not fixed prior to the onset of spawning and unyolked oocytes continue to mature and be spawned during the spawning season (Hunter *et al.*, 1992). The mean relative fecundity (ovary free mass) is 160 ± 12 and 306 ± 25 eggs.g^{-1} for *M. capensis* and *M. paradoxus*, respectively (Osborne *et al.*, 1999). Given that identification of a predetermined spawning batch is probably impossible for Cape hake, the only useful information of their fecundity is the number of eggs produced in a single spawning batch, i.e. batch fecundity (Hunter *et al.*, 1992). Even though both Cape hake species spawn during the same time of the year, they are able to maintain themselves as pure and separate species by spawning in different areas (Botha, 1973, 1974; Payne & Punt, 1995) and different water depths (Botha, 1973). During the spawning season the catch per unit for Cape hake decreases (Payne, 1946; Jones & Van Eck, 1967; Botha, 1973; Gordoa *et al.*, 1995) which is attributed to the fact that they spawn in midwaters making them unavailable to bottom trawls (Payne, 1946; Botha, 1973).

E. Hake harvesting

Harvesting of demersal fish in South Africa is carried out by three separate fishing sectors namely, the deep-sea, inshore and mid-water trawl fishery (Booth & Hecht, 2000). Deep-sea trawl fishery comprises 84% of the total annual catch targeting mainly Cape hake species *M. capensis* and *M. paradoxus*. Inshore trawl fishery targets only *M. capensis* and mid-water trawl fishery targets mainly horse mackerel (*Trachurus trachurus capensis).* During mid-water trawling the main bycatch species are chub mackerel (*Scomber japonicus*) and ribbonfish (*Lepidopus caudatus)* (Booth & Hecht, 2000). In 1998 the total allowable catch for Cape hake was 151 000 tonnes. There are numerous bycatch species that are caught incidentally by demersal trawl fishery (Booth & Hecht, 2000). Cape hake fillet are considered fully utilised (Punt, 1994) whereas bycatch species caught in the demersal sector are considered to be under-utilised (Japp *et al.*, 1994; Booth & Buxton, 1997; Booth & Punt, 1998).

F. Potential quality retaining methods for hake

Probably the most significant problem in quality preservation of frozen fish would be controlling the initial oxidation reaction before the polyunsaturated fatty acids (PUFAs) can begin to propogate (Vareltzis *et al.*, 1997). Another reason why the preservation of fish is a major concern could be attributed to the fact that fresh fish muscle provides an excellent substrate for microbial development, thanks to its favourable water activity, neutral pH and high level of soluble nutrients (Engelbrecht *et al.*, 1996). The flesh of fish such as hake are known to toughen on frozen storage. This is probably related to the enzymatic breakdown of trimethylamine in the muscle to dimethylamine and formaldehyde, the formaldehyde presumably reacting with the protein molecules bringing about a change in texture, which may be enhanced by a variation in storage temperature (Avery *et al.*, 1991). Both trimethylamine-nitrogen (TMA-N) and total volatile bases-nitrogen (TVB-N) support shelf life extension (Leblanc & Leblanc, 2001).

Current methods of fish refrigeration, namely refrigeration with ice, refrigerated air, brine, refrigerated sea water and chilled sea water are deemed unfavourable due to severe flesh damage, textural roughness, increased moisture and drip loss, elevated free fatty acid content and decreased protein extractability (Leblanc & Leblanc, 2001). Alternative methods of retaining fish quality have been investigated (Wessels *et al.*, 1972; Avery *et al.*, 1989; Vareltzis *et al.*, 1997; Leblanc & Leblanc, 2001).

There has been increasing concern over the safety of prominent and inexpensive synthetic food additives (sodium bensoate and potassium sorbate) for the treatment of ice used during cold storage (Wessels *et al.*, 1972), including the possible toxicity of these synthetic chemicals used as antioxidants (Vareltzis *et al.*, 1997). Subsequently interest has been focused on the use of natural antioxidants to stabilise fat-containing foods for example Rosemary (*Rosmarinus officinalis* L.), which is regarded as one of the most important natural antioxidant spice extracts used (Vareltzis *et al.*, 1997).

Pérez-Villarreal & Howgate (1991) reported that filleted hake deteriorated faster than whole hake with optimum storage temperatures of -15°C and -24°C, respectively. Chapman *et al.* (1993) also showed that extra-cold storage temperatures (-30°C and -40°C) together with tripolyphosphate treatment resulted in slower all round quality deterioration (slower rates of change in hardness, cohesiveness, dimethylamine production and sensory acceptability) of hake.

Treatments such as storage under CO_2-enriched atmospheres have shown to suppress the production of both TMA-N and TVB-N, increasing the shelf life almost three-fold from both a microbial and sensorial point of view (Ordóñez *et al.*, 2000). Similarly, Pastoriza *et al.* (1996) showed that modified atmosphere packaging (MAP) increased the shelf life of hake slices two-fold with an inhibition in bacterial growth, increase in pH, reduction in both TMA and TVB, a delay in the alterations of the protein functionality and off-odours. MAP treatment of hake slices together with a five minute dip treatment in a 5% NaCl solution further reduced biochemical, microbiological and sensory deterioration as well as reducing exudation as compared to only MAP-stored samples (Pastoriza *et al.*, 1998). Storage of gutted whole hake muscle under a CO_2-enriched atmosphere (60% CO_2 / 15% O_2 / 25% N_2) resulted in better physical, chemical and sensory results as opposed to those stored under normal conditions (under ice and normal air) (Ruiz-Capillas *et al.*, 2001).

A more drastic or severe method of retaining fish quality, irradiation also more commonly known as radurisation, has been used (Avery *et al.*, 1989; Kairiyama *et al.*, 1990). This treatment involves exposure of the fish to a cobalt 60 source for a period of time resulting in a more superior product concerning shelf life, presence of *Pseudomonas* sp. and TVB-N content (Avery *et al.*, 1989; Kairiyama *et al.*, 1990). Dymsza *et al.* (1990) showed that fresh washed red hake mince irradiated at 0.66 and 1.31 kGy doses, respectively, extended its sensory shelf life between 12 to 18 days, respectively, with a total aerobic plate count of less than 10^6 cfu.g^{-1} for up to 13 days longer than the control sample. Valdés & Szeinfeld (1989) determined that cobalt 60 ionising (i.e. 2 kGy, 6 kGy and 10 kGy) radiated frozen hake fillets (*M. merluccius* *hubbsi*), of which the 6 kGy treated fillets showed the best results for both bacterial count and organoleptic quality.

H. Fish-waste

During the processing of fish a large amount of waste is produced, mainly composed of muscle and skin connective tissue with a high nutritional value (Montero & Borderías, 1991). These products are normally used to produce fishmeal, which yields very little economically. It has therefore been proposed that value be added to this collagen-rich product by using it as a functional material in the food industry instead of fishmeal for animal feed. There are numerous industrial and scientific applications in which collagenous material from animals is used, and yet fish has scarcely been studied with this in mind (Gillet, 1985; Hood, 1985; Bailey & Light, 1989). Due to this predicament Montero & Borderías (1990) investigated and showed that hake-waste collagenous material possesses gelifying properties with an increased functionality at around pH 3 and 0.25 M NaCl concentration as compared to hake muscle collagenous material.

Emulsifying capacity is another important functional property in the food industry, which has been studied extensively in myofibrillar proteins (Carpenter & Saffle, 1965; Neelakantan & Froning, 1971; Dawood, 1980) yet only slightly in collagen, particularly fish collagen (Montero & Borderías, 1991). Montero *et al*. (1990) reported that collagen from connective tissue taken from muscle and skin (hake and trout) mainly consisted of type I collagen and that connective tissue from muscle had more cross-links than collagen from connective tissue from skin for both study species (Montero *et al*., 1990).

Protein malnutrition has been an important cause of infant and child mortality in developing countries, and consequently major emphasis has been placed on the processing and the utilisation of protein-rich foods such as fish protein concentrate (FPC), which was successfully used in treating patients suffering from kwashiorkor and other forms of protein-calorie malnutrition (Moorjani, 1982). FPC is regarded as ideal since it is odourless, free from pathogenic organisms, keeps well, non-toxic and no flavour reversion occurs. This odourless fish protein concentrate contains around 80 (Moorjani, 1982) to 97% (Aall, 1982) protein and traces of fat as well as an available lysine content of 9.96 g.100g^{-1} (Moorjani, 1982). Aall (1982) reported that FPC consumption has a double effect since it increases the content of needed nutrients in the diet and at the same time improves the utilisation of the total diet. During the manufacturing of FPC only 4% of protein is lost as opposed to other methods of processing namely, filleting and canning where between 40-60% of the proteins were lost (Aall, 1982).

Pilchard-waste (viscera, heads and tails) can economically be ensiled into animal feed by either one of two processes namely, biological fermentation using a yeast (*Saccharomyces* sp.) and a lactic acid bacteria (*Lactobacillus plantarum*) and a chemical acidification process using inorganic and/or organic acids, which would cost effectively be ideal for small businesses (Faid *et al.*, 1997). This biotransformation of fish-waste into animal feed can therefore be regarded as an ideal alternative to the current fishmeal manufacturing process since it is shown to be economically cheaper.

Bioprospecting, which is the search for commercially valuable genetic and biochemical resources from nature, which is then used to develop new pharmaceuticals and agrochemicals, is another sector of interest, which has enormous potential (Davies-Coleman *et al.*, 2000).

There are few protein resources that appear to be under-utilised and therefore, offer few prospects for further development but certain pelagic and mesopelagic species such as horse mackerel (Barange *et al.*, 1998) and red-eye round herring (Roel & Armstrong, 1992) have shown to be abundant on the South Cape coast and are obvious candidates for increased levels of harvesting, provided suitable gear are developed (Booth & Hecht, 2001). Other deep-water trawl bycatch species are orange roughy (*Hoplostethus atlanticus*) and oreo dories (*Allocyttus* and *Neocyttus* ssp.) (Booth & Hecht, 2001). Booth & Hecht (2000) also reported bycatch species such as seals, whelks, common octopus (*Octopus vulgaris*), certain crab and prawn species (*Scylla seratta* and *Ovalipes trimaculatus)*, red bait and certain seaweeds (Booth & Hecht, 2000).

G. Chemical analysis

G.1 *Proteins*

Fish-waste is a good source of protein for animal nutrition and therefore the conversion of fish-waste into animal silage is a preferable practice thereby creating a market for the production of high nutritional value silage, in turn necessitating the careful control of the degree of proteolysis and lipid oxidation (Dapkevičius *et al.*, 1998). Studies on the changes in lipids and proteins of both acid and biological silages prepared from blue whiting (*Micromesistius poutassou* Risso) indicated that ensiling by biological methods is more promising than acidic methods due to the following factors namely, that there was a remarkable reduction in both protein solubilisation and basic volatile nitrogen as well as that the oils obtained had lower peroxide values (Dapkevičius *et al.*, 1998).

Sotelo *et al.* (1994) reported a direct correlation between decreasing protein solubility and formaldehyde production since the amount of bound formaldehyde increased with time at -5°C, hence resulting in a concomitant decrease in the amount of soluble protein available. Minced muscle of several white-fleshed fish species had considerable amounts of soluble protein, which could still be extracted with water in a 1:20 ratio even after this muscle was washed twice with water and finally with a 0.15 NaCl solution (Wu *et al.*, 1991).

Myofibrils are highly organised muscle structures similar to whole muscle, which are useful for the study of contractile proteins of skeletal muscle (Yasui *et al.*, 1975). Investigation into the thermal denaturation of myofibrillar proteins from pre- and post-spawned hake showed that the myosin denaturation rates were greater for post-spawning than for pre-spawning hake between two thermal temperatures, 40°C and 50°C, respectively, indicating that proteins of fish in a better biological condition (post-spawned) denature more rapidly and completely than does pre-spawned hake (Beas *et al.*, 1991). Later reports by Roura & Crupkin (1995), which are in agreement with that of Beas *et al.* (1991), contributed this to the Ca^{2+} sensitivity of myofibrils from pre-spawned hake being 40% less than that of myofibrils from post-spawned hake. Myofibrils from post-spawned hake also have more active biochemical and functional properties than those from pre-spawned hake and the enzymatic activities at zero time from post-spawned hake were three times that of pre-spawned hake. It is thus clear that the biological condition related to the reproductive cycle influences biochemical and functional properties.

G.2 *Minerals*

Fish flesh is an important source of minerals since it can contain up to 1 mg.100 g^{-1} of K, Na, Cl, Mg, P and Ca and less than 1 mg.100 g^{-1} of Fe, Zn, Cu and I (Paul & Southgate, 1978; Navarro, 1991). Four commercial fish species including hake (*M. merluccius* L.) were investigated to determine what influence incorporating fish bone has on the nutritional significance of Fe, Zn, Cu, Mn, Mg, Ca, P, Na and K (Martínez-Valverde *et al.*, 2000). The amounts of Fe, Cu and Zn were quite low in all four fish species while those of both Ca and P were higher when bone was present and therefore it was shown to be a good source of Mg, Ca and P. Ca and P are necessary to maintain optimal bone development and to prevent growth disorders such as rickets and osteomalacia (Martínez-Valverde *et al.*, 2000). Bone addition can thus be considered an important supplement of the majority of minerals in the diet. Similar chemical analysis on salted roes of both hake (*M. merluccius*) and ling (*Molva molva*) showed that they contained significant amounts of protein (39.1 and 43.6%, respectively) and lipids (14.13 and 14.80%, respectively), which is not surprising since its physiological role is to serve as the fish's reserve centre (Rodrigo *et al.*, 1998). The most important minerals present were Fe, Zn, K and Na.

It is known that it is not possible to chew and digest raw fish bone, however, it is technically possible to process some fish with bone by careful prior homogenisation, obtaining a fish purée which could be incorporated into some manufactured foods, increasing the Ca and P contents and the Ca:P ratio of the meal (Martínez-Valverde *et al.*, 2000).

G.3 *Lipids*

The two products responsible for frozen fish deterioration is formaldehyde (FA) and dimethylamine (DMA) produced through demethylation of trimethylamine N-oxide (TMAO). Low levels of lipid oxidation increases DMA formation whereas oxidation levels ≥ 500 $meq.kg^{-1}$ actually reduces the amount of DMA produced and, similarly, the amount of FA from TMAO (Joly *et al.*, 1997). However, the non-oxidised lipids show very weak inhibitory effects on the production of DMA and FA from TMAO (Joly *et al.*, 1997).

Lipids of the Southwest Atlantic hake (*M. hubbsi*) has a sum percentage of both EPA (eicosapentanoic acid) and DHA (docosahexaenoic acid) accounting for one-third of the total fatty acids present (Méndez & González, 1997). In addition to this, the unsaturated fatty acids, in particular EPA (Méndez & González, 1997; Vareltzis *et al.*, 1997) as well as DHA (Méndez & González, 1997), are responsible for reducing the risk of cardiovascular disease. EPA also reduces triglyceride levels and increases high-density lipoprotein levels in the blood (Vareltzis *et al.*, 1997). Both hake liver oil (Méndez *et al.*, 1996) and raw fish (Méndez & González, 1997) are good sources of both EPA and DHA with the calculated mean value for EPA and DHA per 100 g muscle tissue being 0.09 and 0.35 g, respectively and therefore 230 g of hake fillets is required to satisfy the daily-recommended ingestion of 1 g (Méndez & González, 1997). Neutral lipids (triacylglycerols and esters) of *M. hubbsi* were the most dominant lipid class with palmitic acid (C16:0) and oleic acid (C18:1) being the main saturated and monounsaturated fatty acids, respectively (Méndez & González, 1997).

The free fatty acid formation of lipids from phospholipids and neutral lipids in frozen minced Cape hake (*Merluccius* spp.) at -5°C and -18°C, occurred in a two-phase process involving an initial rapid surge of free fatty acid formation with a concomitant decrease in phosphorous content taking place in the first step followed by a slower free fatty acid formation with a total loss of phosphorous lipids in the final phase (De Koning & Mol, 1990). Samples stored at -40°C, however, involved a single phase free fatty acid formation and a simultaneous loss of phosphorous lipids (De Koning & Mol, 1990). It is also important to note that the decrease in free fatty acid formation was greater for the phospholipids than for the neutral lipids with decreasing temperature (De Koning & Mol, 1990).

I. Thermal and gel forming abilities

The gelifying capability of a small amount (1%) of red hake tissue (known to have the ability of making good salt-free gels) when mixed with winter flounder (known not to possess the ability of producing good salt-free gels) without the addition of NaCl, which is generally thought to be required were investigated (Vareltzis *et al.*, 1989). The results obtained meant that either a small amount of red hake muscle had a predominant effect on the properties of the gel in the presence of a large amount of flounder muscle proteins, or that there was some other factor(s) present in the minced red hake muscle which was capable of modifying the properties of the proteins of the flounder muscle (Vareltzis *et al.*, 1989). Later studies also indicated the differences in the gel forming ability of chicken, pork and hake natural actomyosin as affected by protein concentration, pH and ionic strength (Cofrades *et al.*, 1997). These results showed that there are differences in the characteristics between the hake samples and that of the chicken and the pork, since hake natural actomyosin only formed gels within a very narrow range of protein concentration, pH and ionic strength as compared to chicken and pork natural actomyosin, suggesting that hake protein is more sensitive to changes in environmental factors than that of pork or chicken (Cofrades *et al.*, 1997).

J. Bacteriological and parasitic aspects concerning Cape hake

Fish muscle provides an excellent substrate for microbial development, thanks to its favourable water activity, neutral pH and high level of soluble nutrients (Engelbrecht *et al.*, 1996). Due to immediate deheading and gutting of Cape hake as well as other species of fish after capture, psychrotrophic marine bacteria are introduced into the fish flesh at a very early stage and this together with intrinsic enzymatic activity results in an unacceptable and useless product in a very short period of time (Engelbrecht *et al.*, 1996). Typical skin counts of fresh Cape hake range from 10^3 to 10^6 colony forming units per gram ($cfu.g^{-1}$) and flesh counts of the butt-end from 2×10^3 to 10^6 $cfu.g^{-2}$ (Engelbrecht *et al.*, 1996). Cape hake's microbial population mainly consists of gram-negative bacteria namely, *Moraxella* and *Pseudomonas* (both 60-80%) as well as gram-positive bacteria namely, *Micrococcus* and *Corynebacterium* (both 20-40%) (Engelbrecht *et al.*, 1996; Vennemann *et al.*, 1994). Vennemann *et al.* (1994) further reveals that the genus *Moraxella* (46-57%) dominates during the chilled processing chain and the microbial population is eventually dominated by the genus *Pseudomonas* (34-90%) after several days of storage. *Yersinia enterocolitica* is a gram-negative bacterium, which causes serious gastrointestinal infection in humans (Velázquez *et al.*, 1996). Velázquez *et al.* (1996) isolated various strains of *Yersinia* from refrigerated hake fillets sold in retail stores for human consumption and found that certain of the strains were potentially pathogenic, representing a risk for human health.

The major endoparasites of both Cape hake species *M. capensis* and *M. paradoxus* are the larvae of the nematode *Anisakis* sp. and the trypanorhynch cestode *Hepatoxylon trichiuri* (Botha, 1986b). Infestation by *Anisakis* sp. was high and similar in both species of hake whereas *Hepatoxylon trichiuri* was not as common or apparently pathologically destructive as *Anisakis* and infected *M. capensis* more frequently and intensively than *M. paradoxus* (Botha, 1986b).

K. Policies and legislation

The South African marine environment is showing symptoms of over-exploitation and degradation, which is likely to increase in the foreseeable future and therefore appropriate policies and legislation should be put into place to try and avoid any such occurrences in future (Attwood, 2000). South Africa's most valuable commercial fishery is its demersal fishing industry, which is at present fully utilised and therefore policies and legislation should ensure that present hake stocks are not exploited, leading to future decline in local stocks (Durham & Pauw, 2000). Probably the single most important governmental legislation in place to date concerning marine life and catches thereof is The Sea Fishery Act 12 of 1988 which is an act put into place "*...to provide for the conservation of the marine ecosystem and the orderly exploitation, utilisation and protection of certain marine resources; for that purpose to provide for the exercise of control over sea fishery; and to provide for matters connected therewith*" (Durham & Pauw, 2000).

Major concern is often expressed about South Africa's inadequate monitoring, managing, insufficient knowledge and understanding of its extensive coastline and marine resources to conserve its biodiversity effectively and therefore emerging policies should lay emphasis on enhancing existing resources, infrastructure, co-ordinating ongoing initiatives and recognising the importance of incentives and public education (Wynberg, 1998). To date South Africa has several completed key policies and legislation having relevance to the conservation and sustainable use of marine and coastal biodiversity namely (Wynberg, 1998):

- The Constitution of South Africa, 1996;
- White Paper on a Tourism policy for South Africa, 1996;
- White Paper on Environmental Management Policy for South Africa, 1997;
- White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity, 1997;
- White Paper on a Marine Fisheries Policy for South Africa, 1997;
- White Paper on a National Water Policy for South Africa, 1997;
- Draft White Paper on Integrated Pollution and Waste Management for South Africa, 1998; and
- Draft White Paper for Sustainable Coastal Development, 1999.

Catch quotas are derived from estimates of the production of individual stocks, based on size, structure and growth rate (Attwood, 2000). Dumping of trawl catch discards into the ocean can have a negative impact on the benthic layer of the ocean since discards sink to the bottom where they rot and reduce oxygen levels, resulting in less suitable habitats for many benthic organisms (Attwood, 2000).

The flow diagram in Figure 1 shows that the Minister of Environmental Affairs and Tourism, who is advised by the Sea Fishery Advisory Committee, is fully responsible for setting the levels of total allowable catch (TAC) for the South African hake stock (Payne & Punt, 1995). An independent Quota Board allocates individual quotas to companies and TAC's and quotas are decided for hake in June of each year (Payne & Punt, 1995). Non-government scientists who should have much greater input in the decision-making process concerning everything affecting South Africa's marine biodiversity is at the receiving end of the decision making pyramid which in effect makes forming key policies and legislation very ineffective (personal observation).

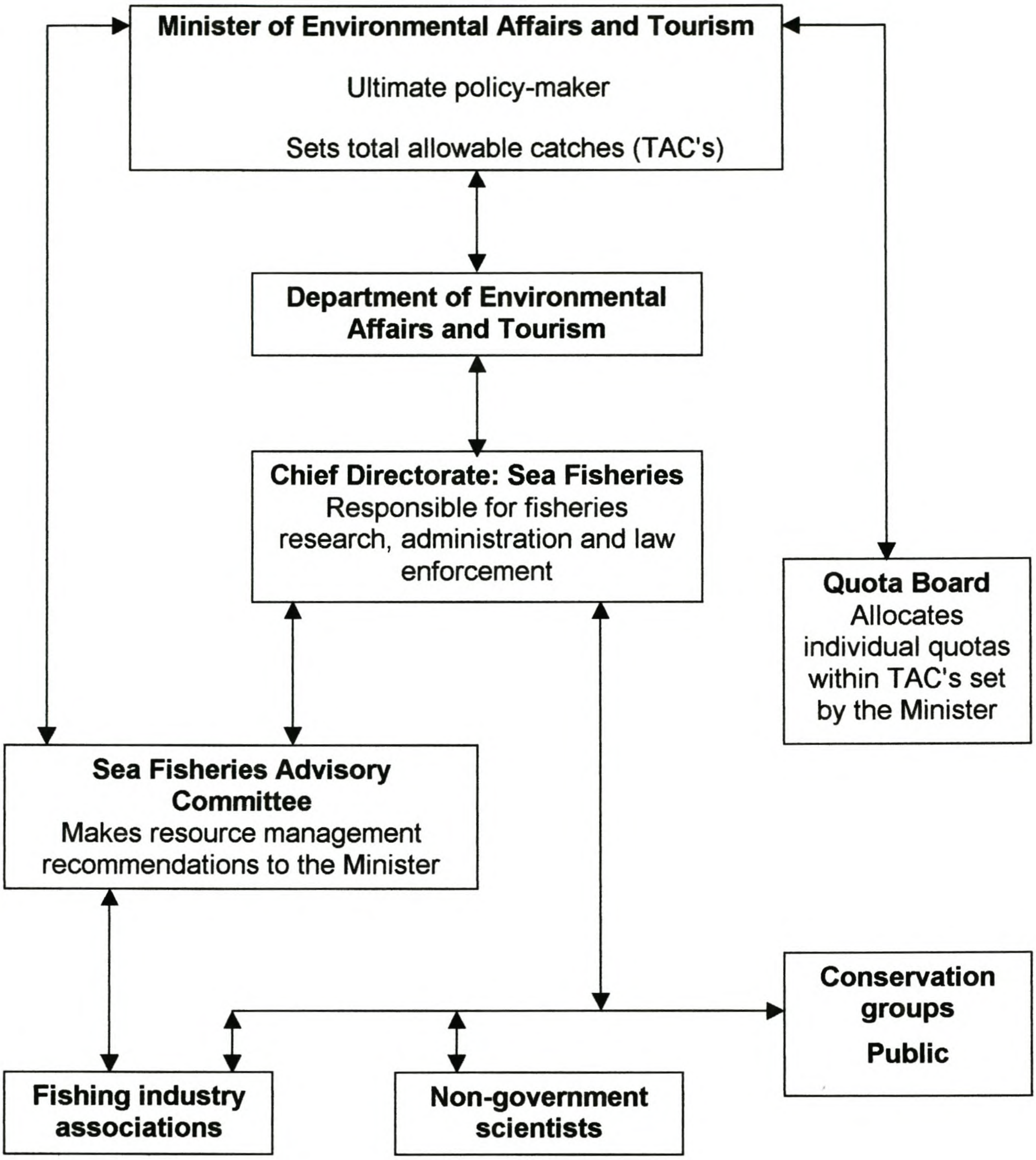

Figure 1. The current fisheries management in South Africa.

L. Conclusions

Cape hake (*Merluccius capensis* and *M. paradoxus*) consist of two separate species, similar in appearance, and is not made up of a single species as was originally thought to be the case. This is attributed to several morphological differences between them which exist namely, total dorsal and anal soft-ray counts, vertebrae count, otolith structure and gill-raker pigmentation. Both species are opportunistic predators, preying heavily on fish, as they get older from a diet dominated by anchovy in their juvenile stages. Their spawning has been described as a double wave, firstly in November/December by both species concerned and secondly in February/March which is mainly dominated by the *M. paradoxus* species. They are regarded as serial spawners and thus possess an indeterminate fecundity (the annual fecundity is not fixed prior to the onset of spawning and unyolked oocytes continue to mature and be spawned during the spawning season). It is evident that spawning affects the biological condition of the hake since their reproductive cycle influences their biochemical and functional properties.

Probably the most significant problem in quality preservation of frozen and fresh fish would be controlling the initial oxidation reaction before the PUFA's begin to propogate. This can be attributed to the fact that fish muscle provides an excellent substrate for microbial development, due to its favourable water activity, neutral pH and high level of soluble nutrients. Fish bone is a good source of Mg, Ca and P and thus bone addition can be considered an important supplement of the majority of minerals in a mineral deficient diet. During fish processing large amounts of waste are produced, with a high nutritional value and thus it has been proposed that value be added to this collagen-rich waste product by using it as a functional material in the food industry instead of fishmeal for animal feed.

It is an unwritten rule in the hake fishing industry that Cape hake is to be deep sea trawled during the day while the majority of the hake shoals reside on the ocean floor (personal observation). The South African marine environment is over-exploited with this degree of degradation increasing in the foreseeable future and thus appropriate policies and legislation should be drafted to try and avoid any such occurrences in future. Major emphasis should be placed on improving local existing resources, infrastructure and corporate incentives. In conclusion non-government scientists should have much greater input in the decision-making process concerning matters affecting South Africa's marine biodiversity in order for future key policy and legislation drafts to be effective.

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Chapter 3

Observation of harvesting procedure onboard a commercial wet-fish hake trawler and preliminary morphological measurements of hake- (*Merluccius* ssp.) waste

Abstract

Practices regarding the current harvesting procedure of Cape hake (*Merluccius capensis* and *M. paradoxus*) off the Port Elizabeth coastline, onboard a commercial wet-fish hake trawler was evaluated (09/04/2001 to 11/04/2001). These evaluations were extended to the secondary grading and processing of the harvested hake after landing. Morphological measurements (i.e. length, breadth, height and mass) of the discarded hake heads were obtained. The company specialized in processing both Perfect Quality (PQ) and Headed & Gutted (H & G) hake, dumping all waste produced during the processing procedure overboard. Electronic scales could be used for the weighing of the hake heads whilst the lengths of the hake heads, presently rated by visual judgement, should preferably make use of graded workbenches to obviate potential shortcomings for objective and accurate categorisation of landed hake. This study indicated that there is a positive correlation between hake head length and hake head breadth, height and mass. Of the two parameters the length of the hake head is more suitable as the decisive parameter, as it will economically be more feasible. This study confirms that dragging should take place during the optimum time of the day (i.e. 07:00 - 17:00) and should not exceed the allocated time of *ca.* 2 hours to ensure that favourable size fish are caught.

Introduction

Trawled non-marketable fish-waste is normally discarded due to time, money and effort constraints required for onboard preservation, resulting in a waste of a potential protein source (Clucas, 1996). Japp (1996) reiterates the importance of this protein wastage by reporting that the South African trawling industry has recently shifted towards a shorter trawl duration, thereby improving the quality of fish caught, increasing the escapement of fish (less net clogging) as well as increasing utilisation of bycatch species. Onboard fish preservation techniques and investigation of the potential chemical composition of this currently discarded material, could result in informed decisions of future matters concerning its disposal.

The lack of sufficient research on the chemical composition of non-commercial material and its suitability for different types of processing before any commercial development can begin was highlighted as one of the key disadvantages facing Iceland's "by-catch bank" (Scudder, 1992).

Preński (1980) reported that the body condition of *M. capensis* catches decreased as the fish length increased. He attributed this to the smaller fish having a higher metabolic rate. Smaller fish had a lower fat accumulation than the larger fish, due to their intensive growth rate, whilst the lower fat values for the medium-size fish was explained by their switch in diet from *Gobiidae* and *Euhpausiacea* to *Merluccius* ssp. as their main food item.

The objectives for this preliminary investigative boat trip, which took place in Port Elizabeth between 09/04/2001 and 11/04/2001 onboard a commercial wet-fish hake trawler, were to determine:

- The hake harvesting procedure (and related constraints) as carried out at sea and where possible make recommendations;
- Morphological measurements (i.e. length, breadth, height and mass) of hake-waste (i.e. hake heads); and
- The secondary grading and processing of hake after landing.

The results obtained would supply necessary data required for techno-economic investigation in the use of hake heads.

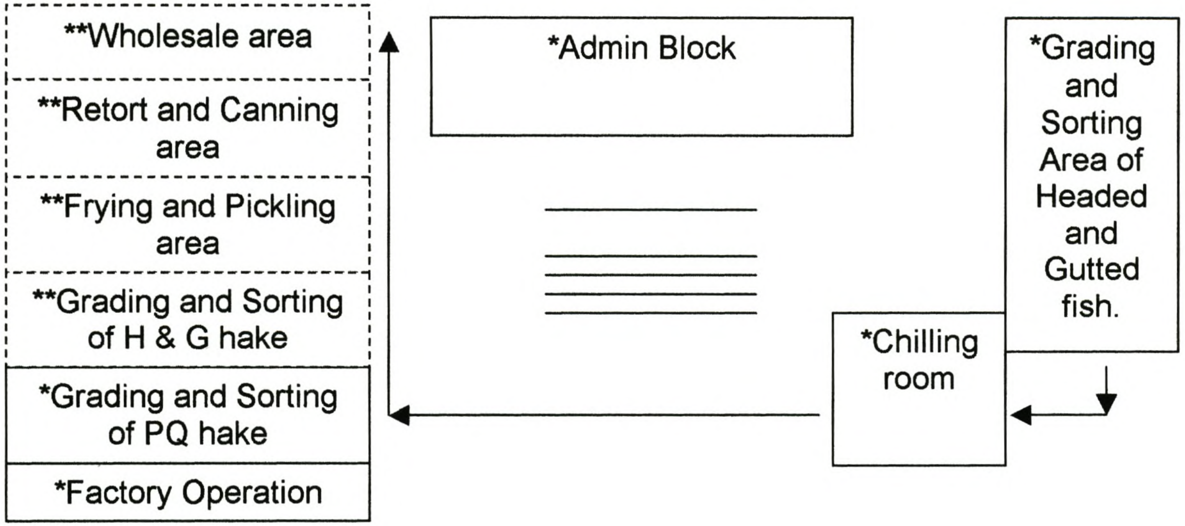
Background (commercial fishing company)

The commercial fishing company mainly concentrates on harvesting hake. Once harvested, the hake is placed into one of two predetermined categories depending on the quality, market and type of processing. The two categories are: Perfect Quality (PQ) hake and Headed and Gutted (H & G) hake. The PQ hake is of a better quality than H & G hake and has a standard weight of *ca*. 1 kg per gutted fish. The PQ hake is only gutted and the head remains attached to the rest of the body. The reason for this is that the foreign markets requested that the hake head remains attached to the rest of the body as it is used as an indicator of freshness for the whole hake. At the same time a better price is gained per kilogram for the export fishing companies as they are paid on a mass delivery basis. The PQ hake destined for foreign markets forms the bulk of Company A's target markets.

The H & G hake is both headed and gutted onboard the trawler. These hake are destined for local markets and are usually of a lesser quality than the exported PQ hake, as the fish are of an incorrect size. Fishing gear, predation in fishing nets and the mishandling of fish onboard the boat are all contributing factors damaging trawled fish (Clucas, 1996). The local market forms a smaller segment of this fishing company's target market.

The PQ hake destined for export is on average three day old hake, which is frozen and packed on the fourth day in polystyrene boxes. The packed hake is flown abroad on the fifth day. PQ hake is inspected by the South African Bureau of Standards (SABS) according to strict specifications as set by the Codex Alimentarius Commission of the FAO/WHO (Food and Agriculture Organisation of the United Nations/World Health Organisation) [Deon Jacobs, Senior Inspector, SABS, Western Cape, personal communication] on day five or six at the international airport before being flown abroad. PQ hake is currently sold at a sales price of R25 per kilogram, each plastic storage bin being able to hold *ca*. 14 kilograms of hake. The main species of hake caught off the Port Elizabeth coastline is *Merluccius capensis (*Shallow-water Cape hake*)* followed by *Merluccius paradoxus (*Deep-water Cape hake*)*.

The present factory layout has the grading and sorting of H & G hake situated outside the main factory building as illustrated in Figure 1. The grading and sorting are carried out by visual inspection. The grading and sorting of PQ hake is done inside the main factory building before being packed into polystyrene boxes. The future layout of the factory will eventually have the grading and sorting of both PQ and H & G hake taking place inside the main factory building. In addition to this, the new section of the factory will consist of a frying, pickling and retort area for the manufacturing of canned pickled fish. The rear of the main factory building will be the wholesale area, which will involve direct retail to the public. Figure 1 shows the layout



* - Existing factory layout.

** - Future factory layout.

Figure 1. Diagrammatic layout of the fishing company's processing unit.

of the existing building with the grading and sorting; frying and pickling; retort and canning; and wholesale areas of H & G hake to be added onto the existing building.

The Marine and Coastal Management (MCM) randomly records the mass per bin of any specific wet-fish trawler's catch brought into the harbour on any given day to determine the whole catch landed. This should fall within the total allowable catch (TAC) quota as determined by the MCM Board. This inspection is also carried out in order to double check that the total mass of the catch harvested corresponds to that of the factory's production output. The whole off-loading process involves a large number of plastic bins being hoisted from the trawler's cold room onto pallets on the quay of the harbour via a forklift truck. Once each pallet is stacked to capacity they are transported to a chill room by means of a mobile crane before further processing takes place.

Harvesting procedure

Payne (1946) reported a decrease in the Cape hake concentration on the sea bed at night, attributed possibly to feeding in midwater, hence making trawling at night an uneconomic proposition. Subsequently, hake is only harvested during the daytime when they are concentrated near the surface of the ocean floor (Botha, 1973, 1974; Hamukuaya, 1994; Huse *et al.*, 1998). On a daily basis, a wet-fish trawler carries out four to five drags each lasting for *ca*. 2 hours (personal observation). A drag is defined as that time during which the net is dragged on the ocean floor.

The trawl net is attached to the rear of the wet-fish trawler (Figure 2). It consists of a trawl section which channels the hake into the cod end section, which is tied into a knot to ensure that the hake is trapped. However, before the catch is hauled all the way into the cod end section at the end, the net rises to the surface due to the buoyancy given to it by the expanded swim bladders, which is in agreement with findings by Payne (1946). The cod end section of the net can harvest *ca*. 15 - 20 tonnes of hake during a single drag. The tied knot in the cod end section is eventually untied to release the harvested hake into the stock-up ponds situated onboard the trawler. The bosum section of the net (Figure 2) is lined with iron, which ensures that the net is dragged along the ocean floor. The float balls create an

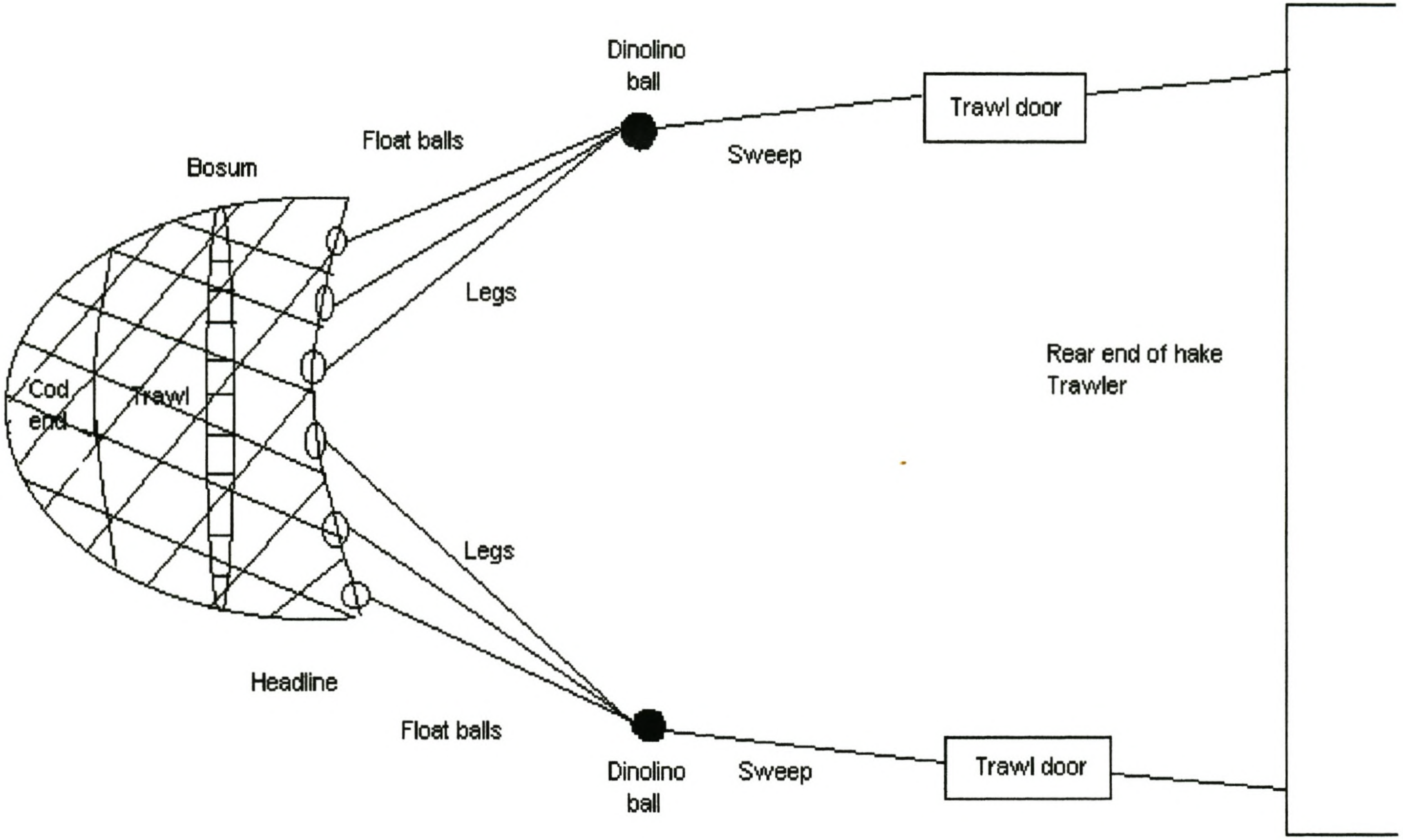


Figure 2. Diagrammatic illustration of the net used during hake harvesting.

opening into the net due to the difference in height created between itself and the bosum. This opening is normally two to three meters in diameter. The dinolino balls are solid iron balls, which are connected to the trawl doors by means of sweeps. The trawl doors ensure the net is spread and kept immersed in the ocean. The warps (i.e. iron ropes) attach the trawl doors to the rear end of the wet-fish trawler.

The length of time it takes to complete a single drag influences the quality of the fish often resulting in damaged hake. This can be explained by the fact that the longer the drag, the more fish gets caught up in the cod end section of the net. This inevitably creates a pressure build up which is exerted on the fish causing physical damage to the fish. The increased concentration of hake also increases the occurrence of cannibalism within the hake species. Hake-on-hake predation is not an uncommon phenomenon since larger *M. capensis* (>60 cm) preys on smaller *M. paradoxus* to a substantial extent where the latter comprises about 25% of the former's total diet (Ware, 1992). Pillar & Wilkinson (1995) concluded that *M. capensis* are opportunistic predators preying heavily on fish, shifting their diets as they become older from one dominated by anchovy and round herring to one consisting largely of horse mackerel and hake. It is therefore clear that the shorter the drag, the better the quality of the catch.

Once the hake is raised out of the ocean, depressurisation causes the hake's swim bladders to inevitably expand, pushing the hake's stomach out by its mouth and this phenomenon gives the fish a bulging stomach appearance, which causes unnecessary stretching of the hake muscle around the abdominal area. This is in agreement with Payne *et al.* (1987) who further suggested that well developed gonads in the abdominal cavity of sexually mature Cape hakes could apply additional pressure on the abdominal area contributing further to stomach eversion.

Processing procedure

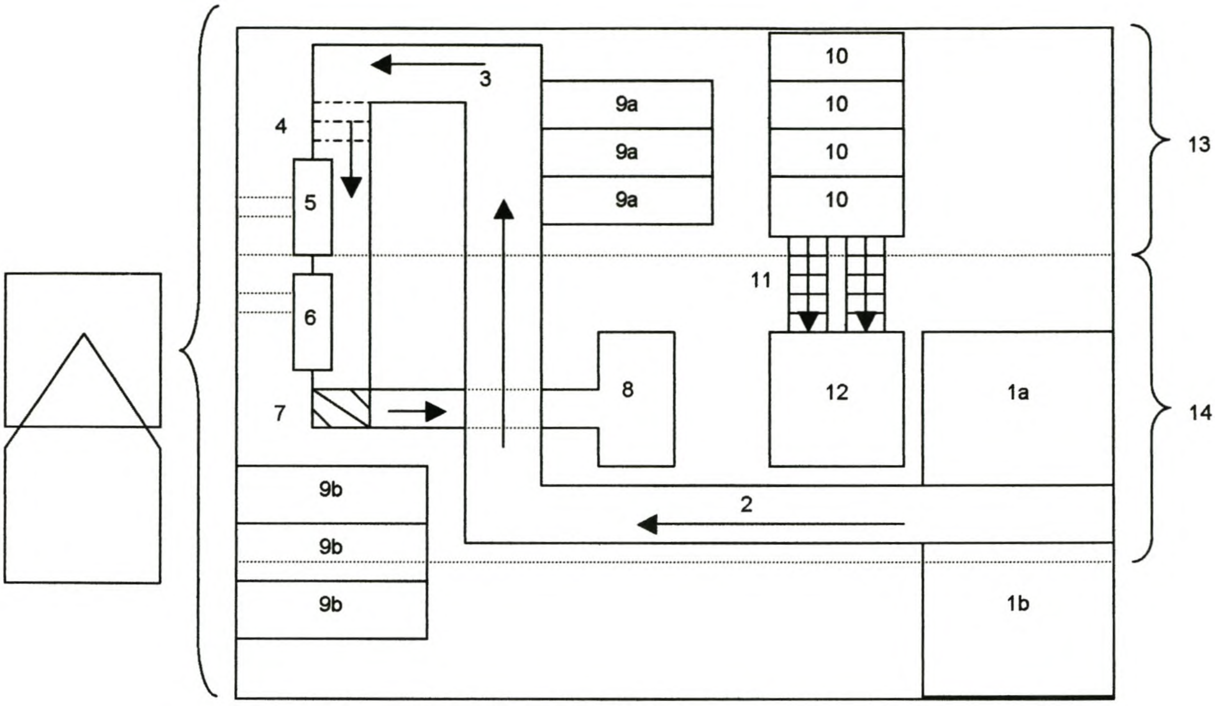
Figure 3 is a diagrammatic layout of the primary processing factory area onboard the trawler. The knot on the cod end section of the net is untied once it is raised directly above either one of the stock-up ponds (no. 1a and 1b in Figure 3) to release the fish into the stock-up ponds. The hake is then transferred via a conveyor belt (no. 2) to the sorting area (no. 3) where the catch is removed and where the hake follows either the PQ or H & G line.

Headed and gutted hake processing procedure (H & G hake)

The hake is transferred to a grooved conveyor belt (no. 4) and deheaded by means of a piano blade (no. 5). The deheaded hake is then gutted (no. 6) after which the hake is known as H & G hake. The hake heads and guts are carried via a shute and dumped into the ocean. The H & G hake is then rinsed in sea water (no. 7) and transferred into a stainless steel bin (no. 8) where after it is packed into plastic bins in alternating layers of crushed ice (no. 10). The packed bins are lowered by means of an elevator (no. 12) into the cold room (no.14), with an ambient temperature of *ca*. -16°C. The cold room has a total storage capacity of *ca*. 90 tonnes of primary processed hake.

Perfect quality hake processing procedure (PQ hake)

Hake passes from stock-up ponds (no. 1a & 1b in Figure 3) via a conveyor belt (no. 2) to the sorting area (no. 3) after which it is placed into stainless steel bins (no. 9a) containing 15 - 20 litres of a sea water and ice mixture (50:50) for *ca.* 30 minutes. This treatment is known as thermo shock and causes contraction of the fish muscle. The temperature maintained during the thermo shock treatment is *ca*. -1 to -2°C. After the thermo shock treatment (no. 9a), the hake is gutted (no. 6) and rinsed in stainless steel bins containing 15 - 20 litres of a sea water and crushed ice (50:50) mixture (no. 9b). The partially processed PQ hake is then packed into plastic bins (i.e. each plastic bin containing *ca*. 14 kg of partially processed PQ hake) in alternating layers with crushed ice (no. 10). The remaining stages in the procedure remain the same as for the H & G hake processing procedure until landing of the hake. Both PQ and H & G hake are stored in the same cold room.



1a + 1b = Stock-up ponds
2 = Conveyor belt
3 = Sorting area
4 = Grooved conveyor belt
5 = Deheading area (Piano blade)
6 = Gutting area
7 = H & G rinsing area
8 = Storage bin
9a = Thermo shock bins
9b = PQ rinsing area
10 = Packing area
11 = Stainless steel rails
12 = Elevator
13 = Ice storage area (below deck)
14 = Cold room (below deck)

Figure 3. Diagrammatic layout of processing factory onboard the wet-fish hake trawler (personal observation).

Discussion

In order to increase yield and ensure quality, several steps could be instituted. The net openings, which are created by the float balls, could be increased from a two or three meter diameter opening to a five meter opening thereby increasing the tonnage hake hauled per drag, and shortening the period the trawl boat is out at sea. This would result in a more superior product regarding freshness and shorten the time it takes to get the hake onto local and foreign markets. The stock-up pond could be equipped with more than one opening onto the conveyor belt since this leads to congestion, resulting in workers manhandling the fish to ensure a constant flow of fish from the stock-up pond to the conveyor belt. This results in damaging and bruising of the catch, which inevitably decreases the value. The existing deheading machine (piano blade) could be equipped to dehead small, medium and large hake since a machine, which is built for the sole purpose of deheading big hake could possibly damage smaller hake during the deheading process. The point of severing the hake head from the rest of the body should be executed closer to the gills since there is still quite a considerable amount of hake muscle attached to the head after deheading.

The factory currently uses visual judgement to grade all landed hake and it is suggested that a more objective and accurate method of categorisation should be implemented. To maximise use of hake-waste the discarded hake head and the roe section of the hake gut should be retained, depending on the availability of space in the cold room. The hake head can be regarded as a possible protein source whereas the roe does have an on land market value.

Morphological Measurements

Materials and methods

Onboard sampling procedure

During each of the four consecutive drags, every twentieth hake head was collected (n=136). The maximum length (cm), breadth (cm), height (cm) and mass (kg) of each hake head collected during the four drags (completed at 09:00, 13:00, 16:30 and 19:50, respectively) were measured. The sample bins of each of the four respective drags were colour coded. Each drag took *ca*. 2 hours.

Morphological measurements

The morphological measurements were executed only once the hake heads were landed. A digital caliper was used for the linear measurement and an electronic platform scale for mass. The length (cm) of the whole hake head was designated as the distance from the tip of the hake head snout to the severed edge immediately behind the pectoral fins (Figure 4). The breadth (cm) and the height (cm), was measured at the point where the head was severed. This should not be confused with the clean head section which is the area from the tip of the snout to the gill covers.

Statistical analyses

Differences in averages were determined using the ANOVA method. The graphs were compiled using Statistica version 6. Each point on the graph indicates the average value calculated from two duplicates in four batches (eight values). The bar indicated at each value represents the 95% confidence interval for the average. A 5% significance level ($p<0.05$) was used as guideline for determining significant differences. For post-hoc tests, Bonferroni was used.

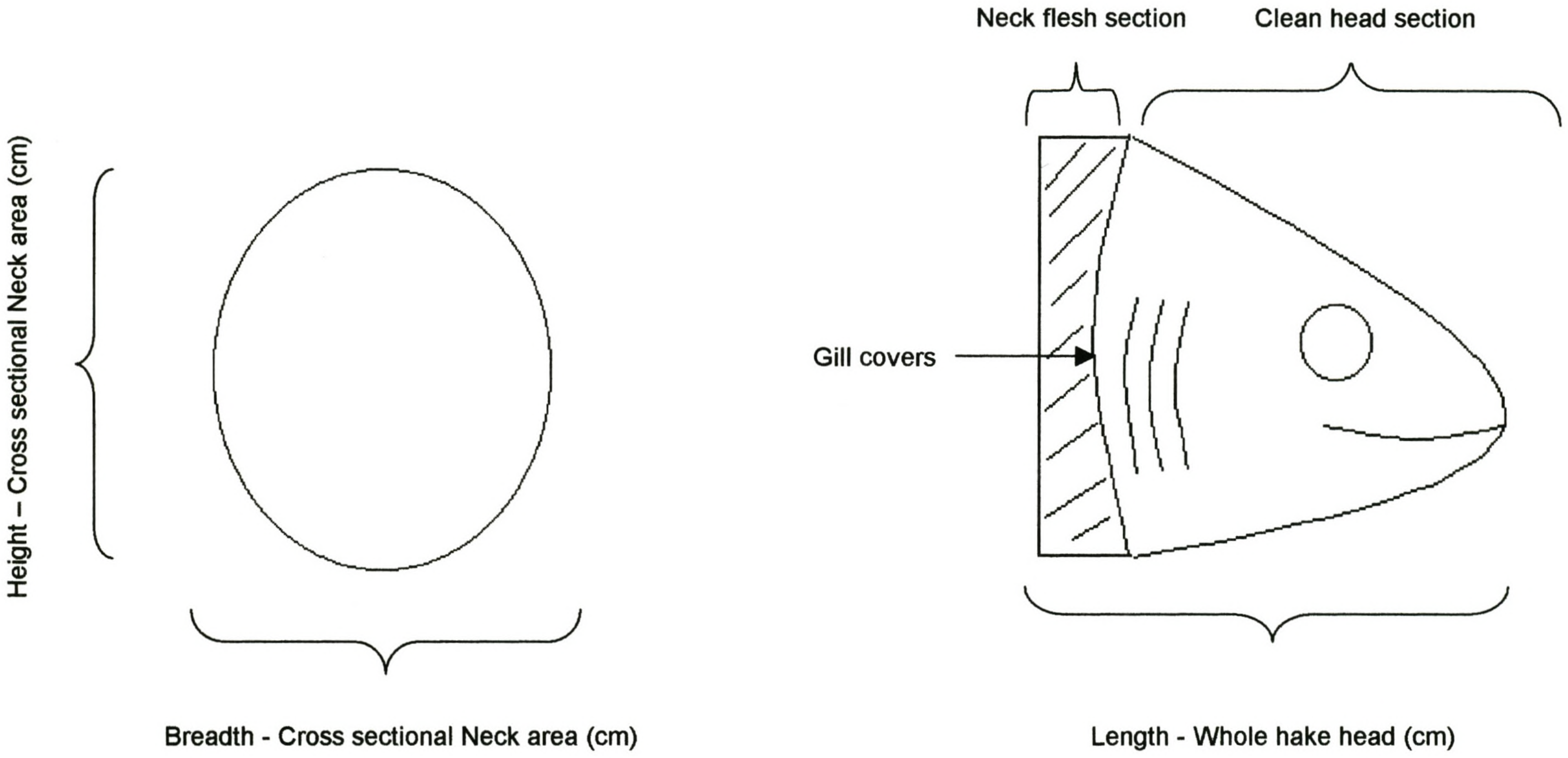


Figure 4. Illustration of the location of the morphological measurement areas of the hake head.

Results and discussion

Figures 5-8 depict the averages of the morphological parameters. Table 1 shows the ranges and average length (cm), breadth (cm), height (cm) and mass (kg) values and Table 2 the Pearson's correlation coefficients for each respective hake head morphological parameter per drag. Detailed results are shown in Appendix 1. From these results it is clear that there is a decrease in the average of each of the four hake head parameters from drags 1-4. The average of drag 1, however, does not differ significantly from drag 2 for the head mass, length, breadth and height ($p=1.00$) and similarly, drag 3 does not differ significantly from drag 4 ($p=0.76$, $p=0.18$, $p=0.81$ and $p=0.80$ for the hake head mass, length, breadth and height, respectively). The averages of drags 1 and 2, however, do differ significantly ($p<0.01$) from that of drags 3 and 4. This can be attributed to the time of trawling (Appendix 1, Tables 1-4) with the first drag hauled onboard the deck at 11:00 and the final drag at 21:50. This can partly be explained by findings of Botha (1974) and Hamukuaya (1994) who both agree that hake shoals concentrate on the ocean floor between dawn and dusk and can therefore be reached by the bottom trawl nets of wet-fish trawlers. The density of these hake shoals near the seabed decrease later at night as they rise to midwaters to feed. The larger hake, however, tend to show minimal vertical migration which can be attributed to a long digestion cycle of 24 hours (Bowman & Bowman, 1980) and to the fact that they do not feed when satiated (Roel & MacPherson, 1988) and are cannibalistic (Pillar & Barange, 1993).

Juvenile to medium size hake migrate vertically to feed in midwaters starting at dusk, peak at noon and decline again at dawn when they migrate back to the seabed. Hake feeds at night in midwaters (Botha, 1973, 1974; Huse *et al.*, 1998) and therefore it is regarded as a general rule to only trawl hake during the day when they are concentrated near the ocean floor in order to optimise the trawl. This prevents juvenile and medium hake being trawled.

In Table 2 the strong positive correlation between each of the hake head morphological parameters ($0.64 \leq r \leq 0.96$) can be seen. This relates well to the findings of Dark (1975) who found that there was an increase in average body

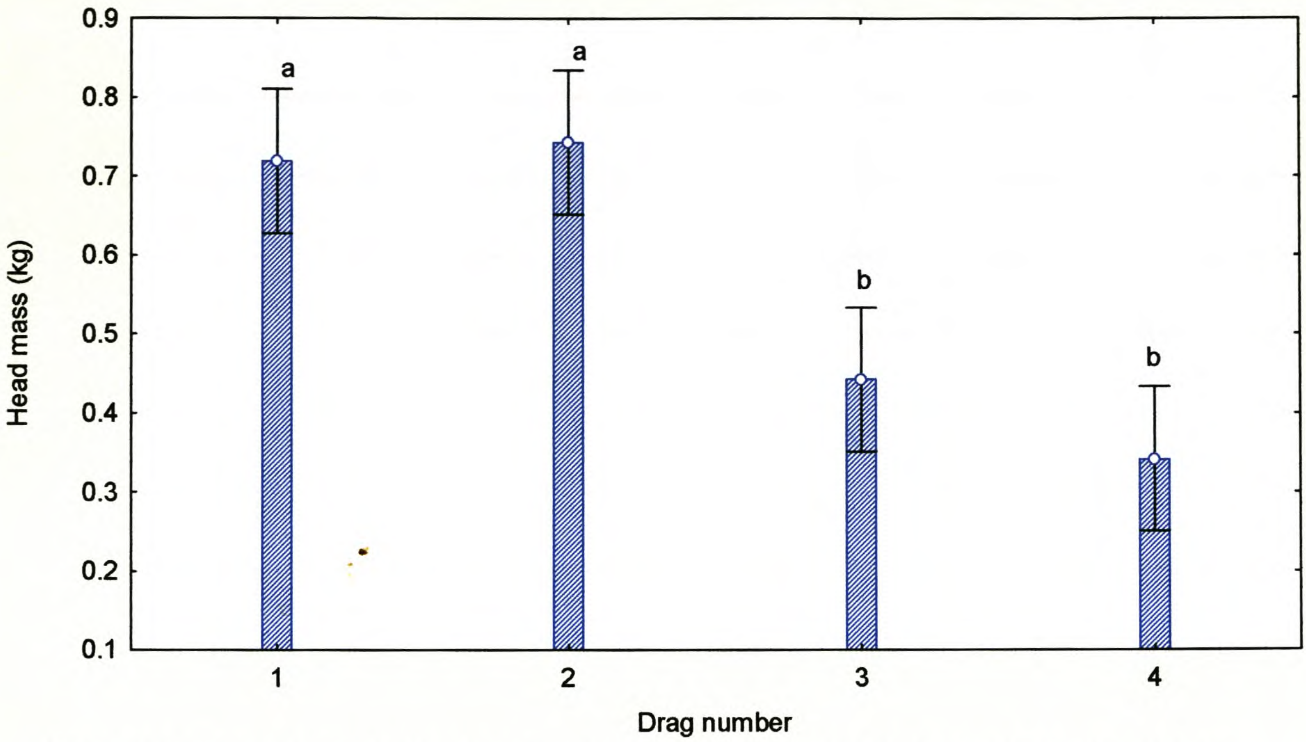


Figure 5. The average hake head mass (kg) for the 4 respective drags. (Averages with different letters differ significantly on a 5% significance level)

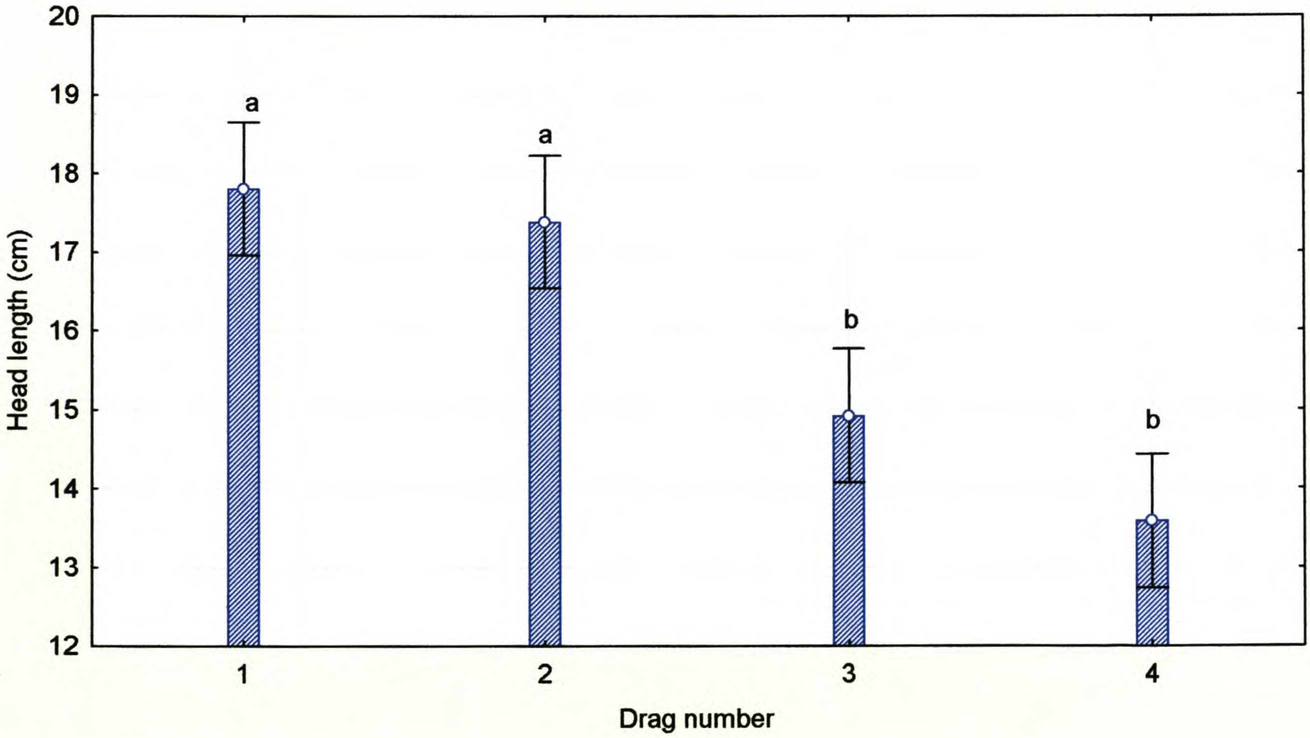


Figure 6. The average hake head length (cm) for the 4 respective drags. (Averages with different letters differ significantly on a 5% significance level)

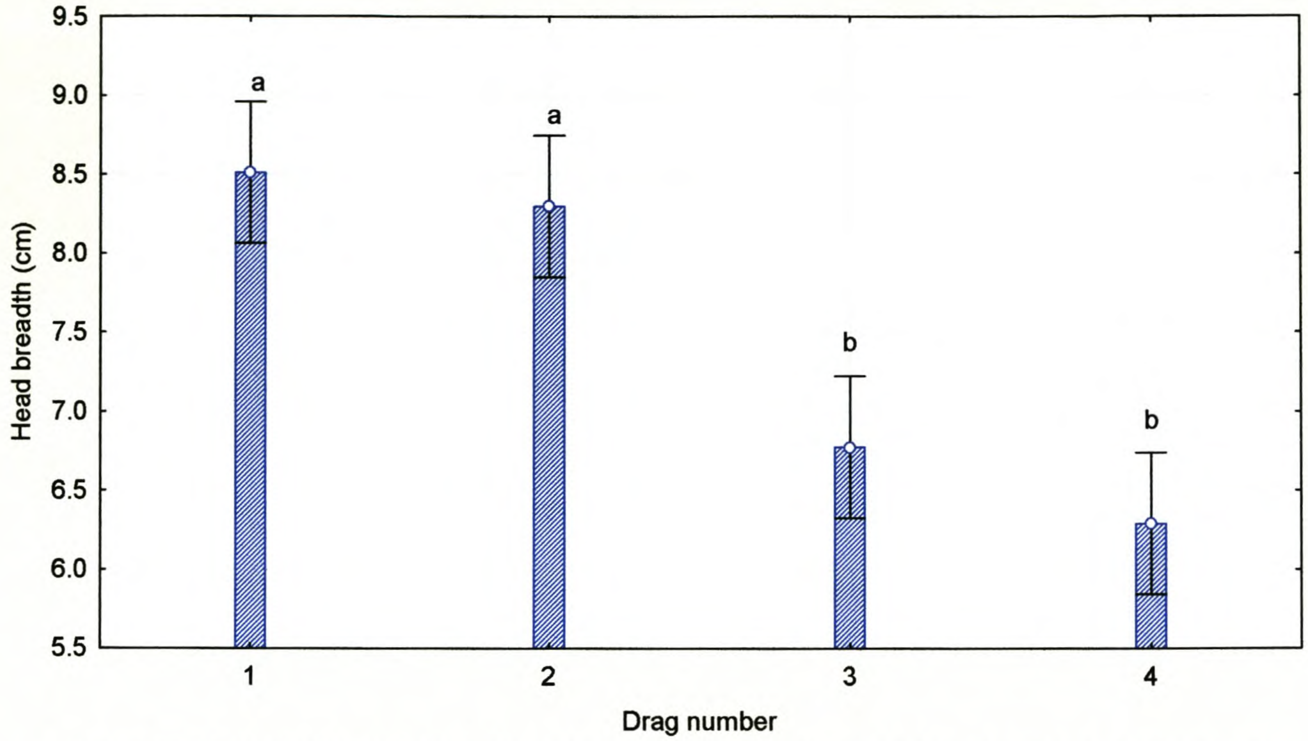


Figure 7. The average hake head breadth (cm) for the 4 respective drags. (Averages with different letters differ significantly on a 5% significance level)

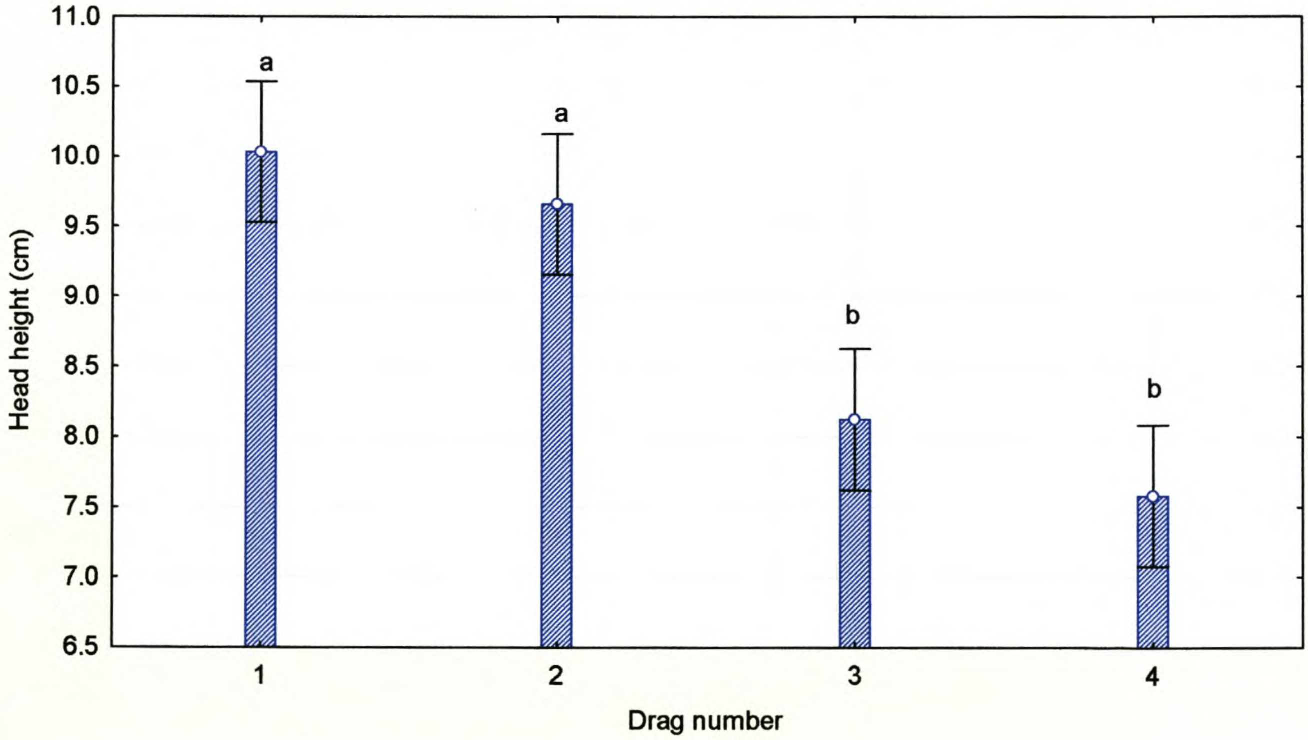


Figure 8. The average hake head height (cm) for the 4 respective drags. (Averages with different letters differ significantly on a 5% significance level)

Table 1. Average length, breadth, height and mass of hake heads sampled during drags 1-4.

Drag #	Average length (cm) [range]	Average breadth (cm) [range]	Average height (cm) [range]	Average mass (kg) [range]
1	17.802 a	8.510 a	10.033 a	0.719 a
	[12.600-24.600]	[5.900-11.800]	[6.700-13.500]	[0.220-1.580]
2	17.381 a	8.298 a	9.661 a	0.743 a
	[12.400-20.700]	[5.900-10.500]	[6.800-12.400]	[0.260-1.260]
3	14.919 b	6.774 b	8.125 b	0.442 b
	[11.600-24.200]	[4.800-9.700]	[5.300-14.200]	[0.160-1.540]
4	13.585 b	6.292 b	7.581 b	0.342 b
	[10.800-20.600]	[4.700-10.600]	[5.900-11.000]	[0.160-1.160]

Averages in the same column with different letters differ significantly on a 5% significance level.

Table 2. Pearson correlation coefficient for drags 1-4 for each respective hake head morphological parameter.

	Drag number	Head breadth (cm)	Head height (cm)	Head mass (kg)
Head length	1	0.87	0.80	0.96
	2	0.77	0.73	0.89
	3	0.86	0.88	0.96
	4	0.85	0.87	0.96
Head breadth	1	-	0.64	0.92
	2	-	0.70	0.89
	3	-	0.82	0.87
	4	-	0.71	0.89
Head height	1	-	-	0.77
	2	-	-	0.78
	3	-	-	0.91
	4	-	-	0.86

weight (g) of Pacific hake (*Merluccius productus*) with an increase in total length of the whole hake. Similarly, one can deduce that the hake heads with the shortest head length will have the smallest breadth, height and mass and vice versa.

Conclusion

By restricting the drag to the allocated time of *ca*. 2 hours the quality of the hake would be increased. This study confirms that dragging should take place during the optimum time of the day (i.e. 07:00 - 17:00) thereby limiting the number of juvenile to medium size hake caught, and affecting a favourable harvest. The current study indicated that there is a positive correlation between hake head length and hake head breadth, height and mass. Graded workbenches were deemed suitable for measuring length and this system is more feasible than weighing. The results obtained from this study would be used to plan subsequent research investigations.

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Chapter 4

Determination of the chemical composition of different sections of the Cape hake head (*Merluccius* ssp.)

Abstract

The chemical composition (i.e. moisture, protein, fat, ash, macro and trace mineral content) of the hake head sections (i.e. neck flesh, clean head, jaw and tongue) of the study population (*Merluccius capensis* and *M. paradoxus*) was investigated. Two lots of randomly selected hake heads were obtained from a commercial fishing company, with the first lot (n=29) being sectioned into three sections (i.e. neck flesh, clean head and jaw) and the second lot (n=53) being further categorised into four hake head sections (neck flesh, clean head, jaw and tongue). The average moisture content, however, of both the neck flesh (82.18%) and clean head (85.55%) sections of the first lot of samples had a higher average than that of the second lot of samples (78.35 and 83.07%, respectively). This decrease in moisture content in the second lot of samples could possibly be attributed to the number of samples in the first lot (n=29) being almost half that in the second (n=53), as the mincing machinery used, required a reasonable sample size resulting in a less homogenous sample for the first lot. The most important hake head section in the first and second lot is the neck flesh section having the highest protein (14.96 and 20.31%, respectively) and fat (0.58 and 1.09%, respectively) content, which is not surprising since hake muscle is a major constituent of this section. The most important hake head section, concerning both macro and trace elements, is the jaw section having the highest concentration of P (211.48 mg.kg^{-1}), Ca (376.43 mg.kg^{-1}), Mg (6.06 mg.kg^{-1}) and Na (15.94 mg.kg^{-1}) macro elements present. Similarly, the jaw had the highest concentration of Pb (182.60 µg.kg^{-1}) and Fe (665.10 µg.kg^{-1}) trace elements present. Concerning chemical composition, the neck flesh section can be regarded as the most important whereas the jaw section could be seen as the most important when one considers mineral content.

Introduction

The Cape hake comprises *M. capensis* and *M. paradoxus*, which are superficially similar in appearance, but have slight morphological differences (Botha, 1974; Cohen *et al.*, 1990a and 1990b; Gordoa *et al.*, 1995). It is therefore likely that the chemical composition will be similar. However, differences might occur between different sections of a single hake head.

Fish-waste is a good source of nutrient (Dapkevičius *et al.*, 1998). Martínez-Valverde *et al.* (2000) showed that *Merluccius merluccius* L. bone is a good source of Mg, Ca and P. Similarly, fish flesh is also an important source of minerals since it contains up to 1 mg.100 g^{-1} of K, Na, Cl, Mg, P and Ca, and Fe, Zn, Cu and I, though in lower quantities (Paul & Southgate, 1978; Navarro, 1991). Whilst bone can not be used as such, it is technically possible to process some fish with bone into a fish purée, which could be incorporated into some manufactured foods (Martínez-Valverde *et al.*, 2000).

The objective of this investigation was to determine:

- ➢ The chemical composition (i.e. moisture, protein, fat and ash content as well as the macro and trace minerals) of the respective hake head sections (i.e. neck flesh, clean head, jaw and tongue) for evaluation as a nutrition product.

Materials and methods

Samples and sample preparation

Two lots of randomly selected hake heads were supplied by the commercial fishing company (different company than that in Chapter 3). The first lot was used to standardise the sectioning and mincing as well as the chemical analyses procedures. The sectioning and mincing procedures were executed at a processing company and the chemical analyses were carried out at the Departments of Food Science and Animal Sciences, Stellenbosch University. The hake heads from the first lot (n=29) were sectioned into three sections, i.e. neck flesh, clean head and jaw. The second lot (n=53) of hake heads (received approximately a month after the first lot) was sectioned similarly but in this instance the tongue was separated from the jaw. After cutting, each section was divided into four batches (if possible). These batches were minced separately before being vacuum packed and frozen. The frozen samples were thawed at 0°C before use. Duplicate analyses were performed on each of the four minced batches of each hake head section.

Analytical assays

Moisture determination

The moisture determination was performed as described by James (1996). Metal dishes containing *ca.* 20 g of acid washed sand and a glass rod were dried in a vacuum oven (68 - 72°C) for 30 minutes before weighing 5 ± 0.01 g of sample into them. The glass rod was used to aid the mixing of the sample with the acid washed sand after which it was placed in a water bath for *ca.* 30 minutes until all excess water had been evaporated from the sample. The metal dishes containing the acid washed sand, glass rod and sample were placed in an air-drying oven (101 - 105°C) for 15 - 18 hours. The difference in mass between the wet and dried sample was calculated, which was then converted into a percentage.

Protein determination

The percentage protein content was determined according to the AOAC Method 2001.11 (AOAC, 2002).

Fat determination

Determination of the percentage fat present in the samples was performed as described by Lee *et al.* (1996).

Ash determination

The ash determination was performed as described by James (1996). The crucibles were dried in a muffle furnace at a temperature of 550°C for 30 minutes before weighing off 5 ± 0.01 g of sample into each crucible. Five ml of magnesium acetate alcohol was, however, added to the sample (to aid the burning process), before gentle heating over a Bunsen burner until the sample was charred. The crucibles containing the charred sample were then transferred to a muffle furnace at 550°C for 15 - 18 hours until a white or light grey ash was formed. The difference in mass between the wet and charred sample was calculated, which was then converted into a percentage.

Mineral determination

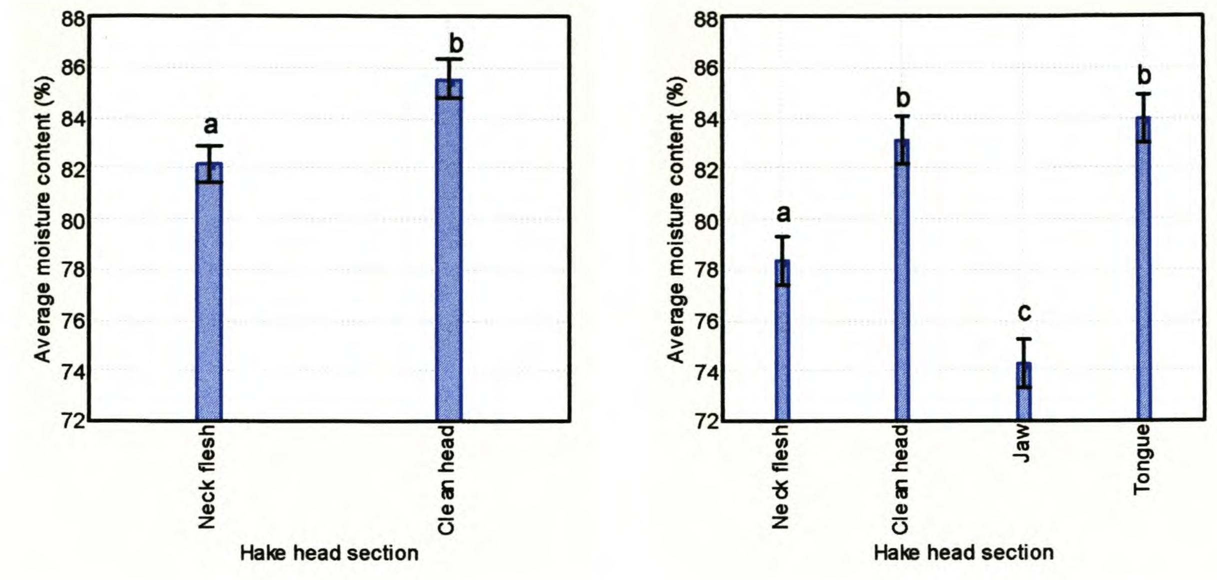
The determination of the percentage macro and trace elements present in the samples was performed by the Department of Physics, Stellenbosch University as described by Watson (1994). Only single analysis were carried out and the results obtained were on a dry mass basis, which was recalculated into an as is result.

Statistical analysis

ANOVA was used to determine significant differences in chemical content between the different sections. The graphs were compiled using Statistica version 6. Every point on the graph indicates the average value calculated from two duplicates in four batches (eight values). The bar indicated at each value represents the 95% confidence interval for the average. A 5% significance level ($p<0.05$) was used as guideline for determining significant differences. For post-hoc tests, Bonferroni was used.

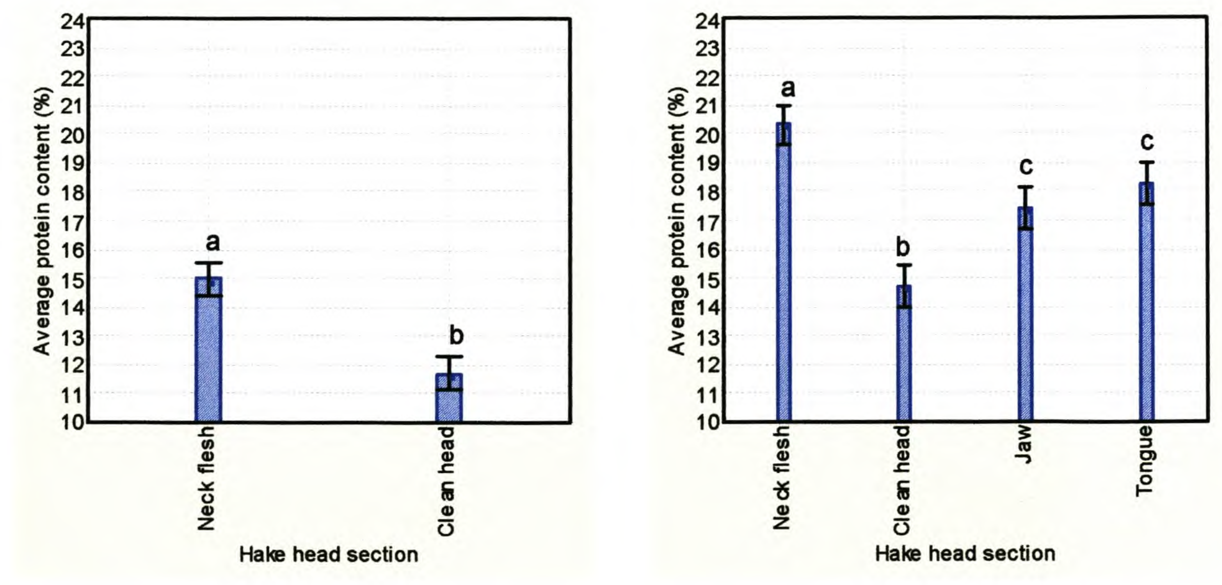
Results and discussion

Figures 1a-4a and 1b-4b represent the average moisture, protein, fat and ash content present in the hake head sections of the first and second lots of samples, respectively. Detailed results are shown in Tables 1-2 in Appendix 2. The jaw section was not included in the statistical analysis of the first lot of samples as, due to insufficient sample, only one batch was chemically analysed. Figures 1a-4a, shows that there is a significant difference ($p<0.01$) between the neck flesh and clean head average moisture, protein, fat and ash content present in each hake head section. In Figures 1a and 4a it can be seen that the clean head section has a higher average moisture (85.55%) and ash (3.24%) content than the neck flesh (82.18 and 2.50%, respectively) section. In turn one can see from Figures 3a and 4a that the neck flesh section has a higher average protein (14.96%) and fat (0.58%) content than the clean head section (11.70 and 0.46%, respectively).



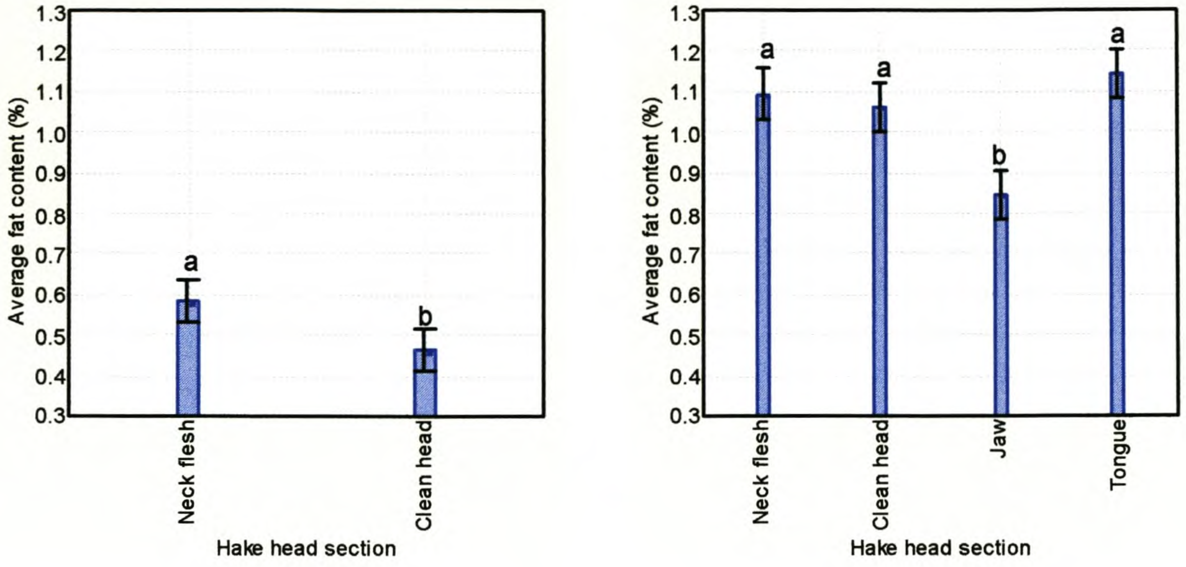
(a) (b)

Figure 1. The average moisture content (%) of the two (a) and four (b) hake head sections for the first and second lot of samples ($p<0.01$), respectively. The letters superimposed on the graphs show significant differences on a 5% significance level.



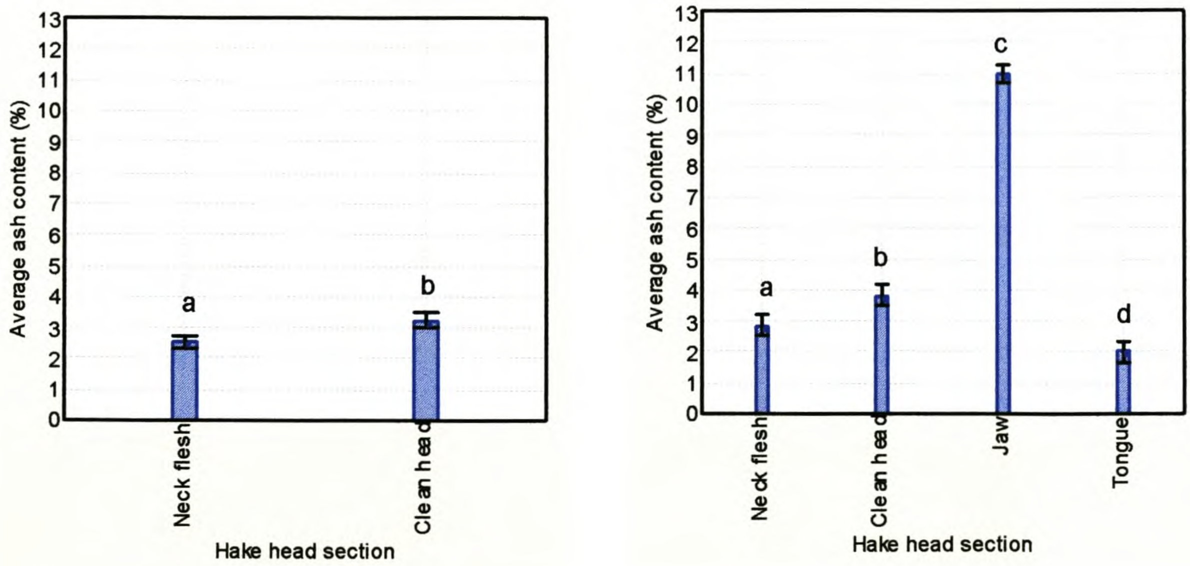
(a) (b)

Figure 2. The average protein content (%) of the two (a) and four (b) hake head sections for the first and second lot of samples ($p<0.01$), respectively. The letters superimposed on the graphs show significant differences on a 5% significance level.



(a) (b)

Figure 3. The average fat content (%) of the two (a) and four (b) hake head sections for the first and second lot of samples ($p<0.01$), respectively. The letters superimposed on the graphs show significant differences on a 5% significance level.



(a) (b)

Figure 4. The average ash content (%) of the two (a) and four (b) hake head sections for the first and second lot of samples ($p<0.01$), respectively. The letters superimposed on the graphs show significant differences on a 5% significance level.

No significant difference (p=1.00) was found between the moisture content of the clean head (83.07%) and tongue (83.97%) sections (Figure 1b), while there was significant differences (p<0.01) when comparing the remaining hake head sections with one another. The average percentage protein present in each of the hake head sections differed significantly (p<0.01) except between the jaw and tongue sections (p=0.61) (Figure 2b). There was also no significant difference found between the average fat content present in the neck flesh and clean head (p=1.00), neck flesh and tongue (p=1.00) and clean head and tongue sections (p=0.33), as seen in Figure 3b, whereas the jaw section differed significantly (p<0.01) from each of the aforementioned sections. There was a significant difference (p<0.01) in the average ash content present between each of the hake head sections (Figure 4b) of the second lot of samples with the jaw now included.

In Figures 1b and 2b one can see that the jaw section had the lowest average moisture (74.29%) and highest ash (10.98%) content, which was expected since collagenous bone is a major constituent of the jaw. From Figures 1b and 3b it can be seen that the tongue section had both the highest moisture (83.97%) and fat (1.15%) contents, whereas Figure 2b indicated that the neck flesh section had the highest protein (20.31%) content which is expected due to the fact that hake muscle forms a major constituent of this hake head section.

Similar trends were observed when comparing only the neck flesh and clean head sections between the first and second lot of samples with the only exception being no significant difference (p=1.00) in the average fat content between the neck flesh and clean head sections of the second lot of samples (Figure 3b).

Further grading of the hake heads from three to four sections resulted in an increase in the average protein, fat and ash content for the neck flesh (14.96 to 20.31%, 0.58 to 1.09% and 2.50 to 2.84%, respectively) and clean head (11.70 to 14.70%, 0.46 to 1.06% and 3.24 to 3.82%, respectively) sections. The average moisture content, however, of both the neck flesh (82.18%) and clean head (85.55%) sections of the first lot of samples had a higher average than that of the second lot of samples (78.35 and 83.07%, respectively). This decrease in moisture content between the two lots could have possibly been attributed to the fact that the number of samples in the first lot (n=29) was almost half that of the second (n=53) and knowing that the mincing machinery used, required a reasonable sample size resulting in a less homogenous sample in the first lot as compared to that in the second.

The neck flesh section had the highest protein (14.96 and 20.31%, respectively) and fat (0.58 and 1.09%, respectively) content in both the first and second in comparison with the remaining sections within each respective lot, which could be attributed to the fact that hake muscle constitutes a significant portion of this section.

Figures 5-9 depicted the content of macro elements and Figures 10-12 that of the trace elements present in each of the hake head sections of the second lot of samples. Detailed results are shown in Tables 3 and 4 in Appendix 2.

In Figures 5, 7, 8 and 9 it can be seen that the jaw section had the highest percentage of the following macro elements namely: P (211.48 $mg.kg^{-1}$), Ca (376.43 $mg.kg^{-1}$), Mg (6.06 $mg.kg^{-1}$) and Na (15.94 $mg.kg^{-1}$) which could be attributed to the fact that collagenous material is a major constituent of this hake head section. These results are in agreement with similar findings by Martínez-Valverde *et al.* (2000) for the three former macro elements. The neck flesh section, however, had the highest K (9.53 $mg.kg^{-1}$) content (Figure 6), a result similar to that of Paul & Southgate (1978) and Navarro (1991). From Figures 5-9 it can be seen that the tongue section had only traces of the macro elements present. Figure 11 and 12 indicated that the jaw section had the highest amount of Pb (182.60 $\mu g.kg^{-1}$) and Fe (665.10 $\mu g.kg^{-1}$) present whereas the tongue section had the highest level of Zn (201.14 $\mu g.kg^{-1}$) present (Figure 10).

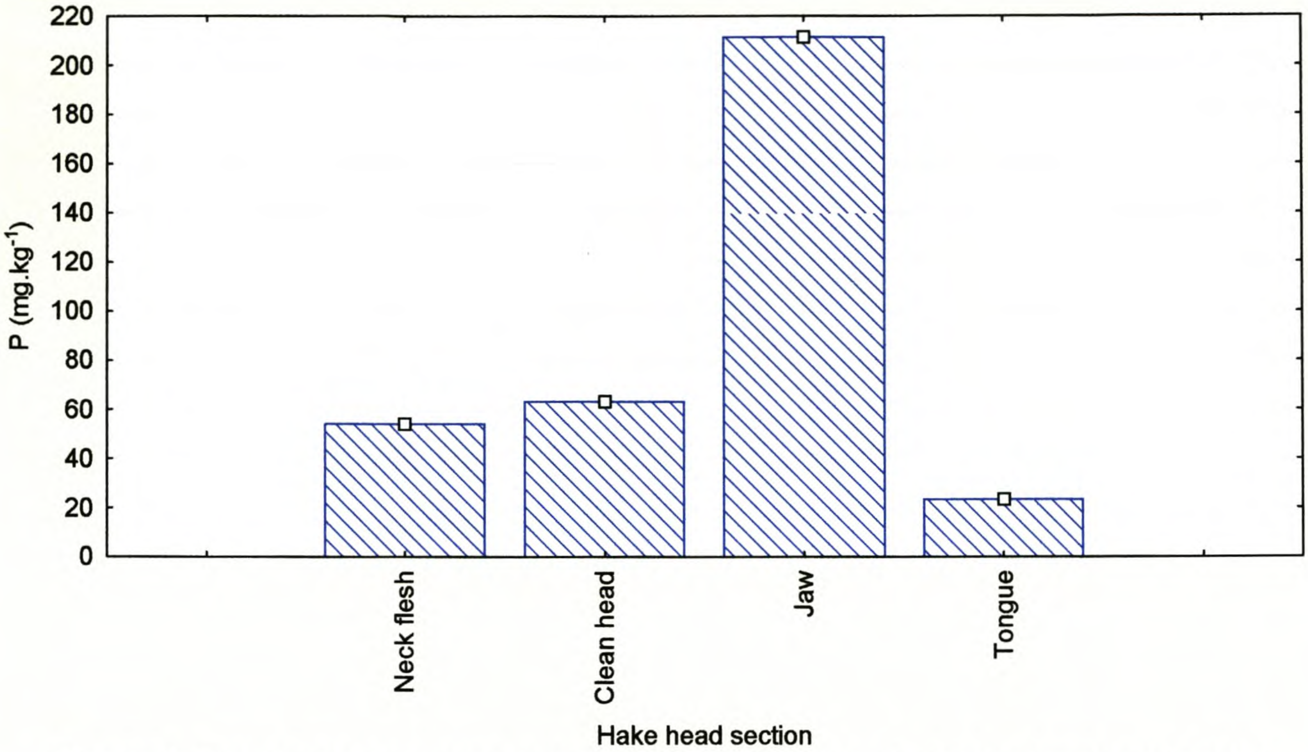


Figure 5. The phosphorus content (mg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

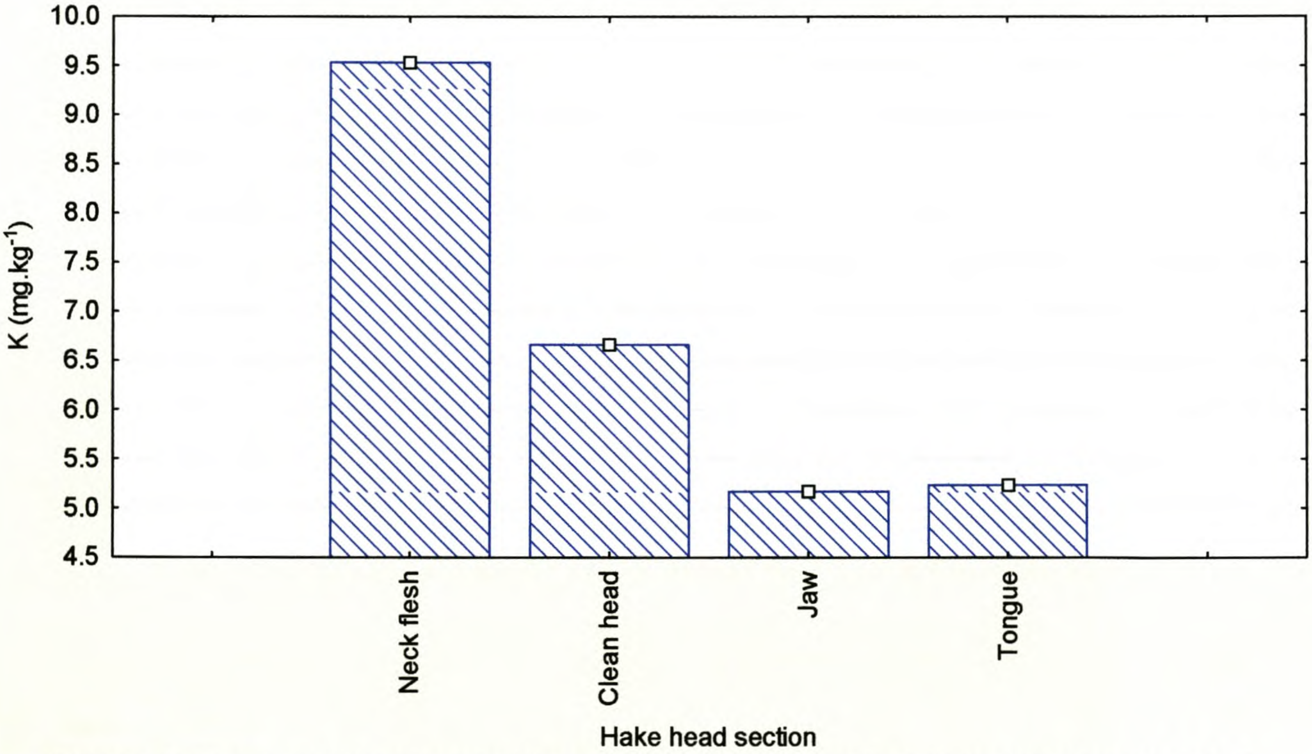


Figure 6. The potassium content (mg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

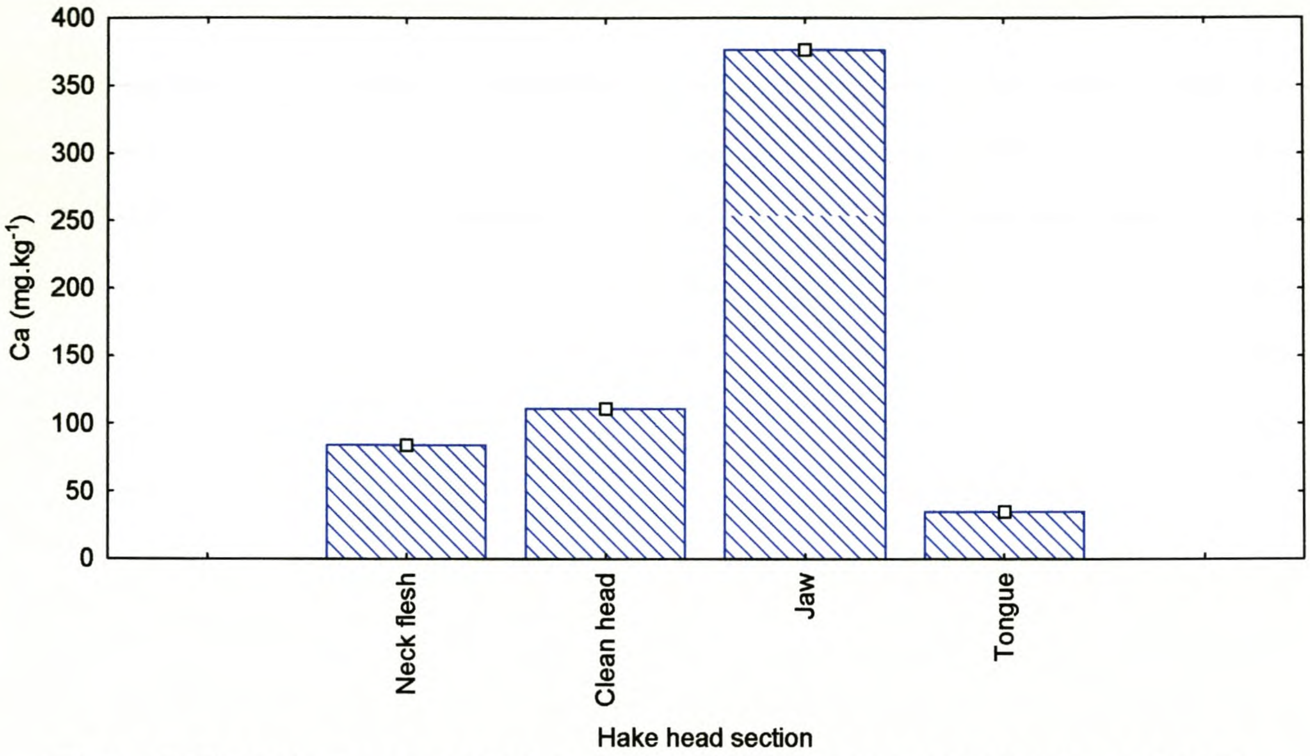


Figure 7. The calcium content (mg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

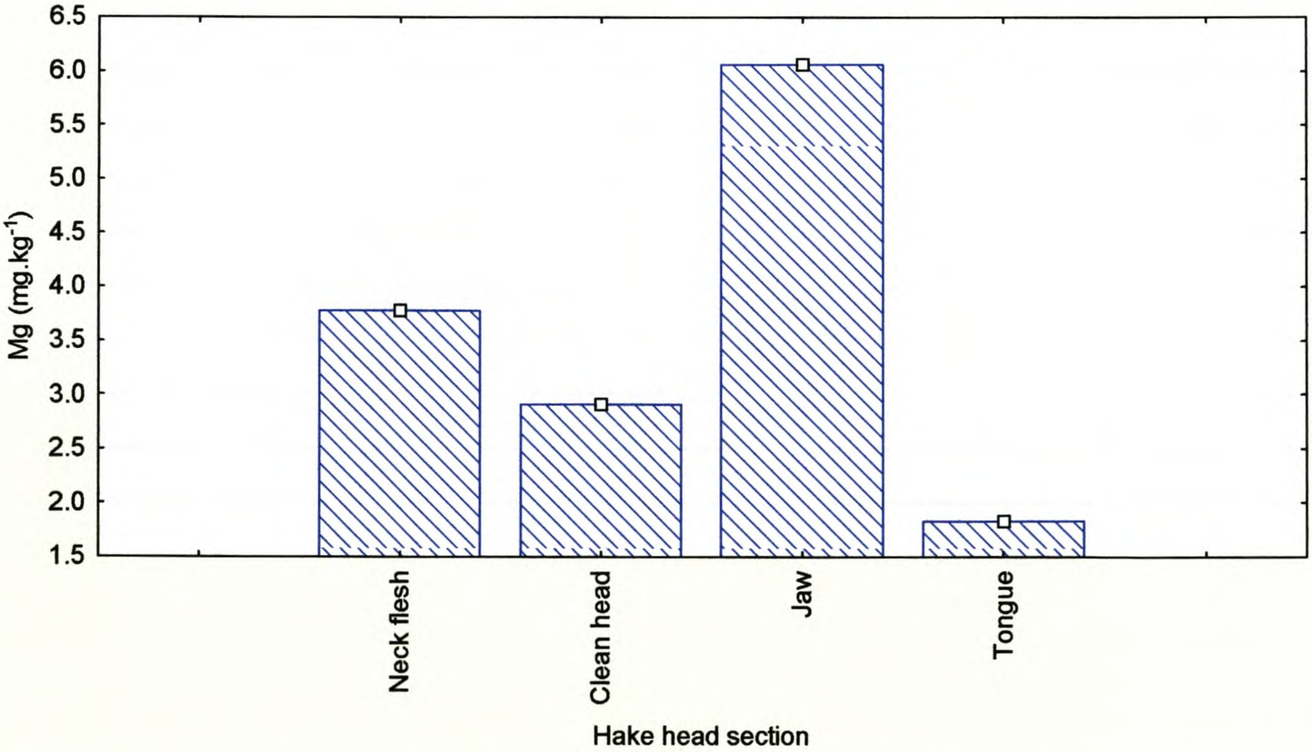


Figure 8. The magnesium content (mg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

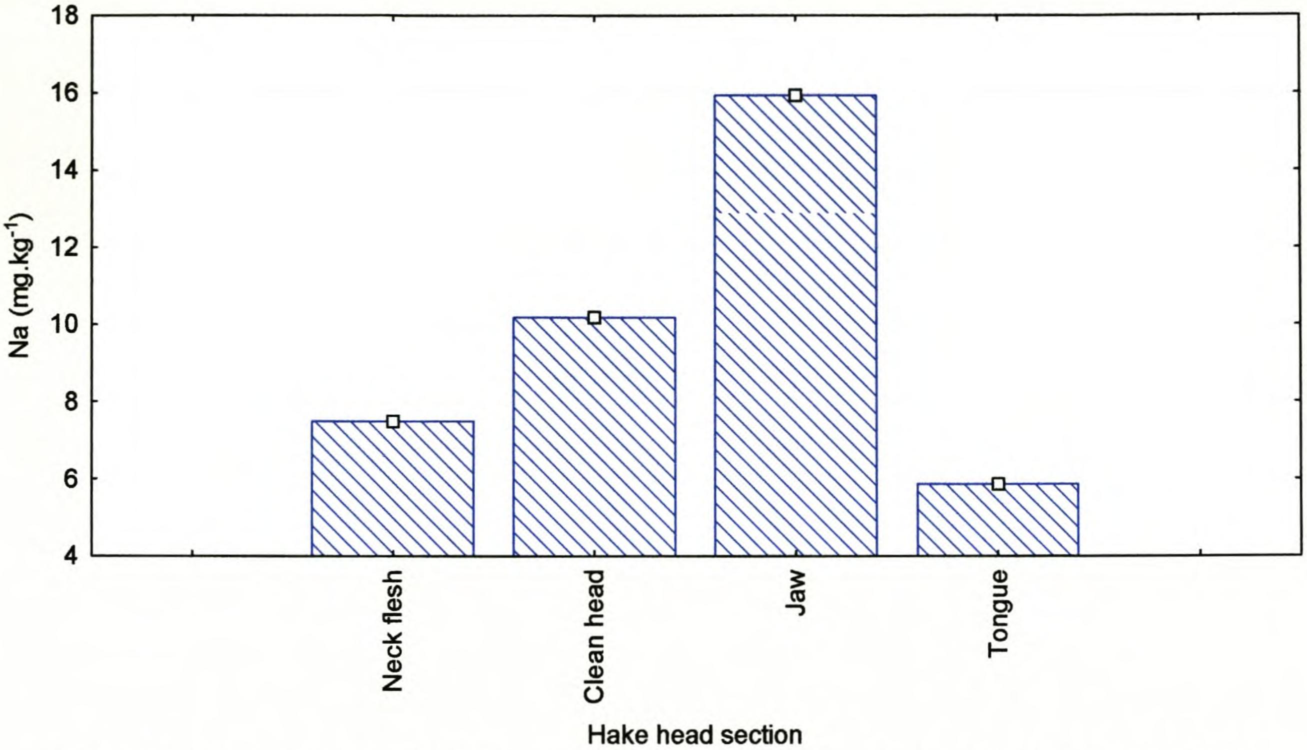


Figure 9. The sodium content (mg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

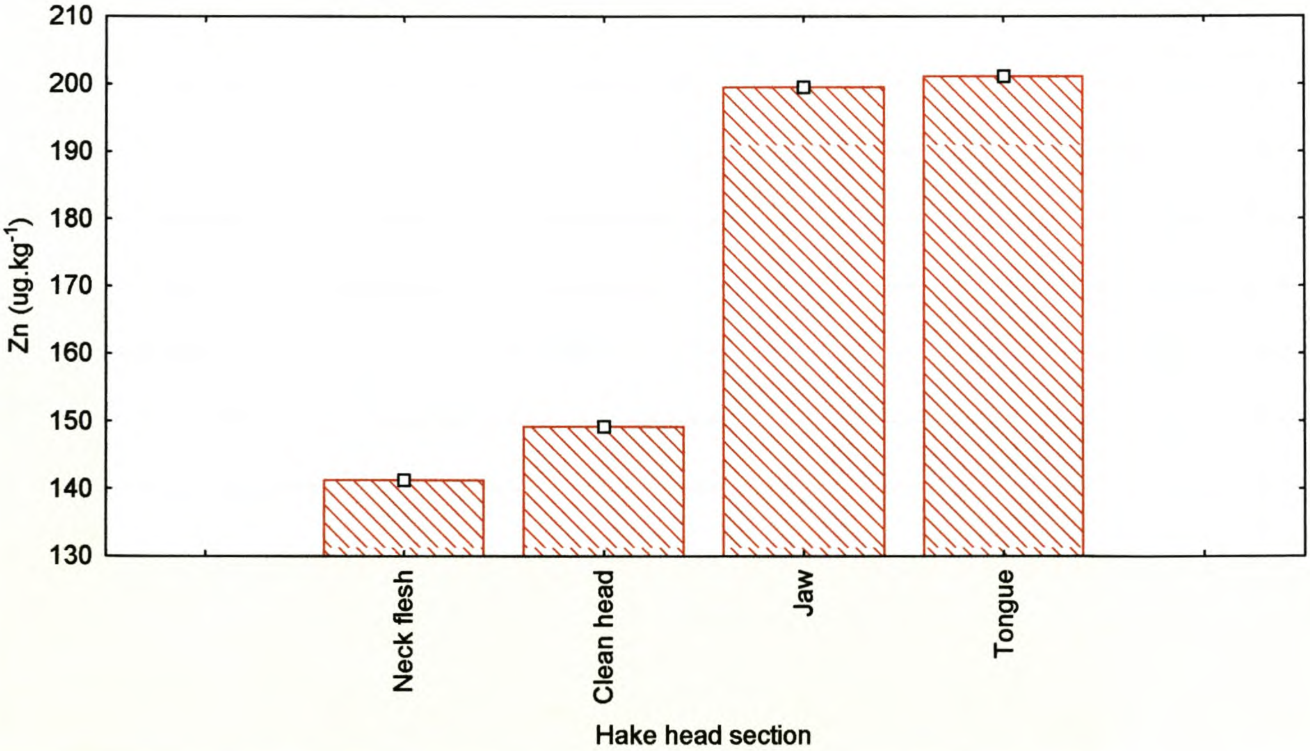


Figure 10. The zinc content (μg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

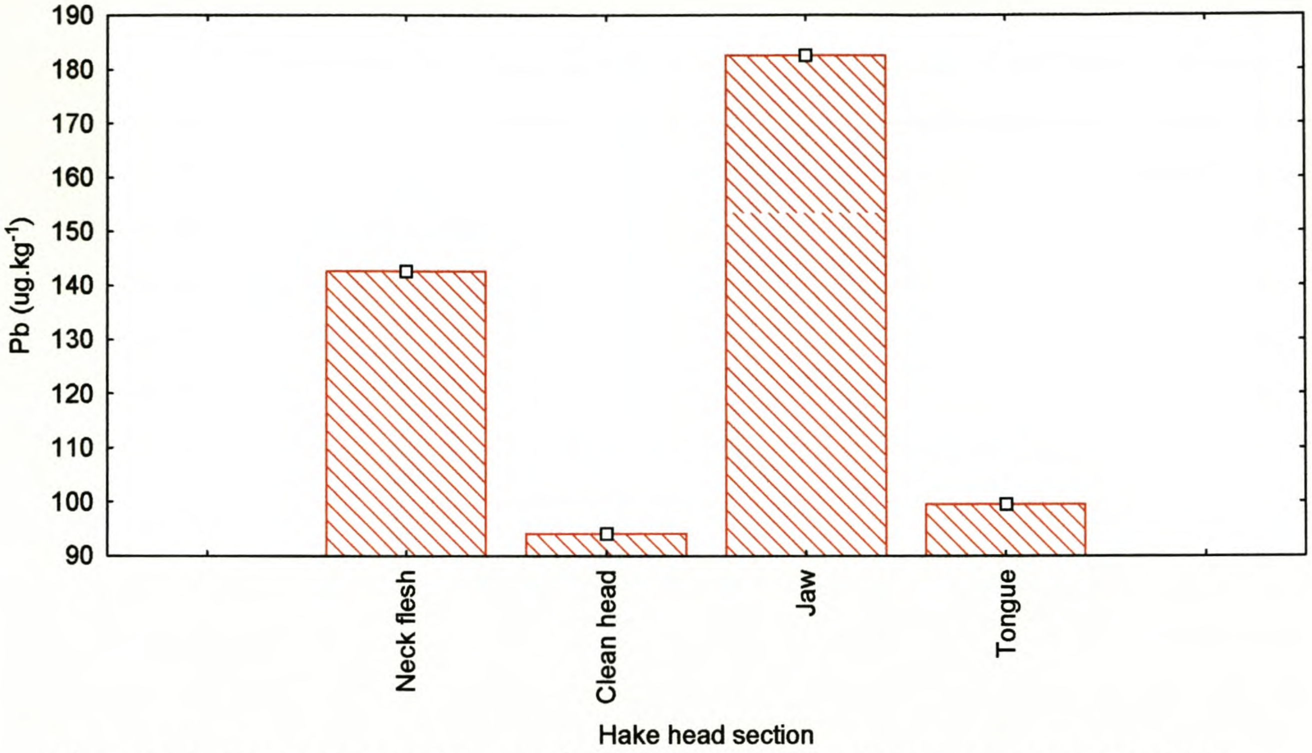


Figure 11. The lead content (µg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

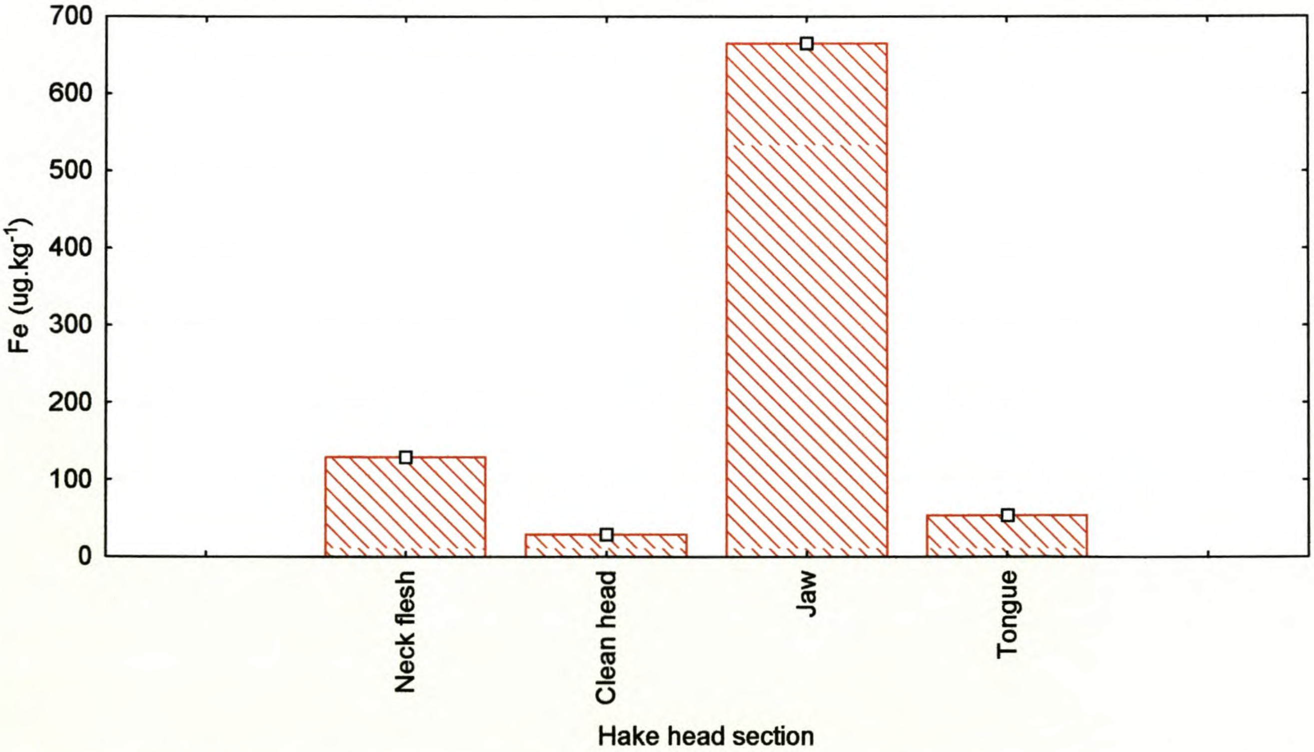


Figure 12. The iron content (µg.kg^{-1}) in each of the four hake head sections of the second lot of samples.

Conclusion

The hake head sections within the first lot of samples indicated that both the protein and fat content was inversely proportional to the moisture with the exception of the ash content. It was surprising to see that there was a positive correlation in both sections concerning the ash content since logic would predict that a higher moisture content would result in a lower ash content and vice versa as was the case in each of the four sections within the second lot of samples. The neck flesh in the second lot is a good example of the inverse proportionality between the moisture content and both the protein and fat content. This trend did, however, not follow throughout in the remaining sections. One can therefore regard moisture determination as a key analytical procedure since it affects the ash, protein and fat content of the sample, which is important to keep in mind when considering large-scale commercial production. The jaw section had the highest concentration for the following macro elements namely, P, Ca, Mg and Na, and similarly for both Pb and Fe trace elements analysed. This therefore implies that the jaw section is a potential Ca, Na and Fe source for supplementing diets of people suffering from a Ca, Na or Fe deficient diet. With regard to chemical status the neck flesh section is seen as a good potential source of both protein and fat, which could be attributed to the fact that hake muscle constitutes a major portion of this section. This section could thus be used to supplement the protein and fat of an existing food product, which is protein and fat deficient. Similarly, a market could be created for the production of an economical food product with the neck flesh section being the main ingredient. This food product would then cater for the needs of the bulk of South Africa's population suffering from a protein and fat deficient diet.

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Chapter 5

Development of morphological prediction models for whole hake (*Merluccius* ssp.) and hake-waste

Abstract

Observations were investigated regarding the current large scale harvesting procedure of Cape hake (*Merluccius capensis* and *M. paradoxus*) off the Cape Town coastline. Commercial fishing company B specialises in processing Perfect Quality (PQ), small, medium and large Headed & Gutted (H & G) hake, dumping all waste produced during processing overboard. Morphological measurements (length, mass and H & G hake mass) of whole Cape hake as well as the hake-waste (i.e. hake heads (*Merluccius* ssp.), which are thrown overboard as a result of economic or legal considerations) (length, breadth, height and mass) were recorded. During each of the boat trips, samples were investigated, respectively. Six prediction models were constructed from whole hake and hake-waste morphological measurements made during each of the three boat trips (n=115, n=185 and n=572, respectively). The prediction models constructed showed an increase in the variance of the data points of categories (i.e. predetermined divisions in centimeters into which each whole hake gets placed based on the total length of that hake – measurement taken from the tip of the snout to the tip of the caudal tail) 3 (64 - 80 cm) and 4 (>80 cm) for each of the six respective prediction models, per boat trip, as opposed to categories 1 (30 - 46 cm) and 2 (47 - 63 cm). This could be attributed to the smaller sample sets of categories 3 and 4 or due to an expected increase in variance when investigating larger biological samples. There was a clustering of data in three areas for each prediction model namely; within category 1 and across both categories 2 and 3 and 3 and 4. This emphasizes the latitudinal stratification of the Cape hake population by age, hence the stratification by size. All the prediction models constructed for both boat trips 2 and 3 differed significantly ($p<0.01$) from that of boat trip 1, with the exception of the hake head length (cm) prediction model. This may be attributed to the increased sample sizes sampled during boat trips 2 and 3 as opposed to 1 or to the fact that boat trips 2 and 3 were sampled while the Cape hake were well into their main spawning season while those sampled during boat trip 1 was during the

secondary spawning season or due to a combination of the aforementioned reasons. This variation between the prediction models of boat trips 2 and 3 and those constructed for boat trip 1 can, however, not be attributed to the diurnal feeding habit of Cape hake since all samples investigated were taken during daytime catches. Since data was pooled across geographical areas (increased representation) and an increasing sample size (increased precision) was sampled for boat trip 3 as opposed to boat trips 1 and 2, the prediction models constructed from this boat trip would by the most accurate to use.

Introduction

Most of South Africa's commercially trawled demersal fish has already been partially cleaned (i.e. headed and gutted) before landing and therefore conversion factors (i.e. the ratio of the total weight to total cleaned weight in each sample) for several commercially important fish species, including Cape hake (i.e. *Merluccius capensis* and *M. paradoxus*) have been calculated to be 1.46 (Chalmers, 1976; Fishing Industry Handbook, 2002). The conversion factors calculated for Cape hake, fished in South African waters, partially cleaned into the following products namely; headed & gutted, head-on & gutted, broken, untrimmed skin-on fillets and trimmed skinless fillets are 1.46, 1.10, 1.46, 1.94 and 2.25, respectively. The conversion factors calculated, for hake fished off the Namibian coastline, was the same as that for the respective partially cleaned products caught off the South African coastline with the exception that the Namibian head-on & gutted as classified by the South African market is known here as gutted (conversion factor: 1.04).

These calculated conversion factors are obtained from constructing prediction models for a specific biological species or several different species. This enables one to make quite accurate informed future predictions regarding the study population or any aspect pertaining that specific species. Both prediction models and conversion factors can therefore be regarded as a beneficial asset within the fishing industry since both can be used to make informed decisions to decrease the risk factor involved in decision-making. However, one should bear in mind that calculated conversion factors for a given species are subject to variation between different areas due to variations in biological factors (i.e. availability of food and maturity state of fish) and cleaning processes (Chalmers, 1976).

Cape hake spawning can be described as a double wave, firstly in November/December by both species concerned and secondly in February/March which is mainly dominated by the *M. paradoxus* species (Botha, 1986). These species generally exhibit a diurnal (day and night) vertical movement, lying on the ocean floor during the day and moving into midwaters at sunset (Botha, 1973, 1974; Hamukuaya, 1994; Huse *et al.*, 1998). However, their feeding intensity decreases during the spawning season (less pronounced diurnal vertical feeding migration-concentrates on ocean floor during the day and feeds in midwaters at night) (Roel & Macpherson, 1988). It is important to bear in mind that Cape hake are opportunistic feeders, which will exploit suitable prey when encountered rather than feeding at specific times of the day or night (Pillar & Barange, 1997).

The two major fishing companies in South Africa namely, Irvin & Johnson (Pty) Ltd. and Sea harvest (Pty) Ltd. categorise their hake trawled according to a "Six" and "Zero Small System" where either the total length (mm) or the mass (g) of the partially cleaned hake is used (Fishing Industry Handbook, 2002).

The objectives of this study were to:

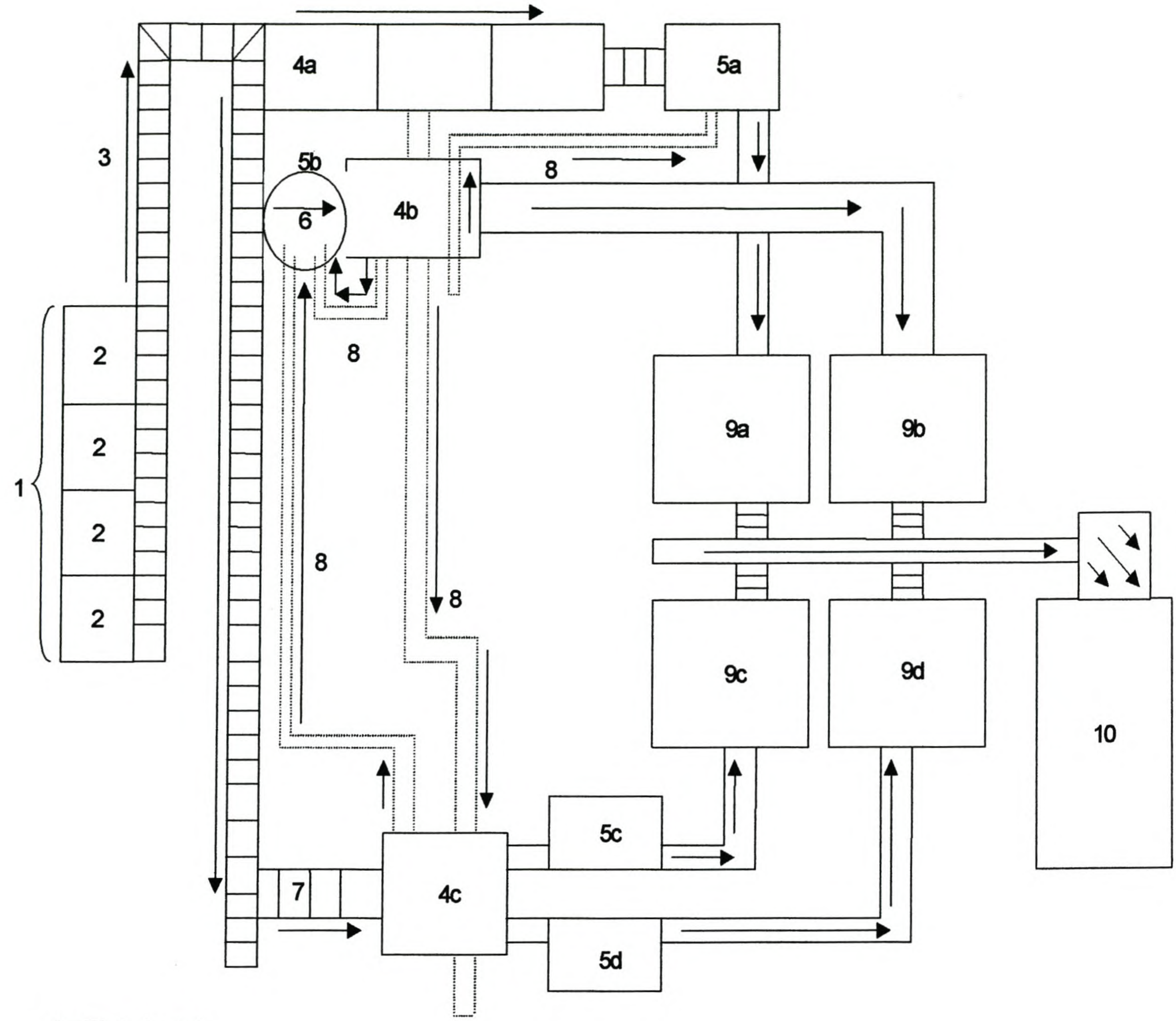
- Observe large scale hake harvesting procedure as carried out at sea and where possible make recommendations;
- Record morphological measurements (length, mass and Headed & Gutted hake mass) of whole hake;
- Record morphological measurements (length, breadth, height and mass) of hake-waste (i.e. hake heads); and
- Construct morphological prediction models for whole hake and hake-waste.

Harvesting procedure

The harvesting procedure onboard two wet-fish trawlers were observed in Cape Town from 25/08/2001 to 26/08/2001, 12/10/2001 to 17/10/2001 and 07/02/2002 to 12/02/2002, respectively. The first of the three turnarounds took place onboard wet-fish hake trawler A and the second and third onboard wet-fish hake trawler B. The first boat trip was only done over 2 days due to strike action by workers at this company's main processing factory.

Four drags were executed daily, each drag lasting for *ca.* 3 hours, in a single turnaround period of six days. Both wet-fish hake trawlers A and B have identical primary processing areas for the hake trawled. The difference between the wet-fish hake trawler of the first commercial fishing company in Chapter 3 and hake trawlers A and B of the second commercial fishing company is that the fish processing onboard the two latter wet-fish trawlers is far more intensive, each having a total of 14 workers, in the hake processing factory area, including the Factory manager. A diagrammatic layout of the processing factory onboard the trawlers is shown in Figure 1. The net used to harvest the hake from the ocean is similar to that used by the wet-fish hake trawler of Company A. Once the net is hauled onto the deck, it is opened over the fish hatch area (Figure 2) at the rear end of the trawler below the deck area. The entire hake processing area is situated below the deck area.

Although the desired species trawled is hake, a range of diverse fish is often hauled (Figure 3). The fish hatch area is sub-divided into four stock-up ponds (Figure 4), each with its own separate opening onto the conveyor belt (Figure 5). Each stock-up pond is opened separately and emptied before the next one is opened. The fish harvested is then conveyed via a conveyor belt to the beginning of the processing line where the Factory manager separates the hake from the bycatch (Figure 6). The bycatch is either retained for further processing or, depending on the specific species of bycatch, discarded back into the ocean via a shute system (Figure 7). The separated hake continue on the conveyer belt for further processing and classing, either as Perfect Quality (PQ), large Headed & Gutted (large H & G), medium Headed & Gutted (medium H & G) or small Headed & Gutted (small H & G) hake.



1=Fish hatch
2=Stock-up pond
3=Conveyor belt
4a-4c=Gut buckets
5a-5d=Wash ponds
6=Piano blade
7=Barder machine
8=Shoot system
9a-9d=Chill tanks
10=Fish room

Figure 1. Diagrammatic layout of processing factory onboard wet-fish hake trawlers A and B.

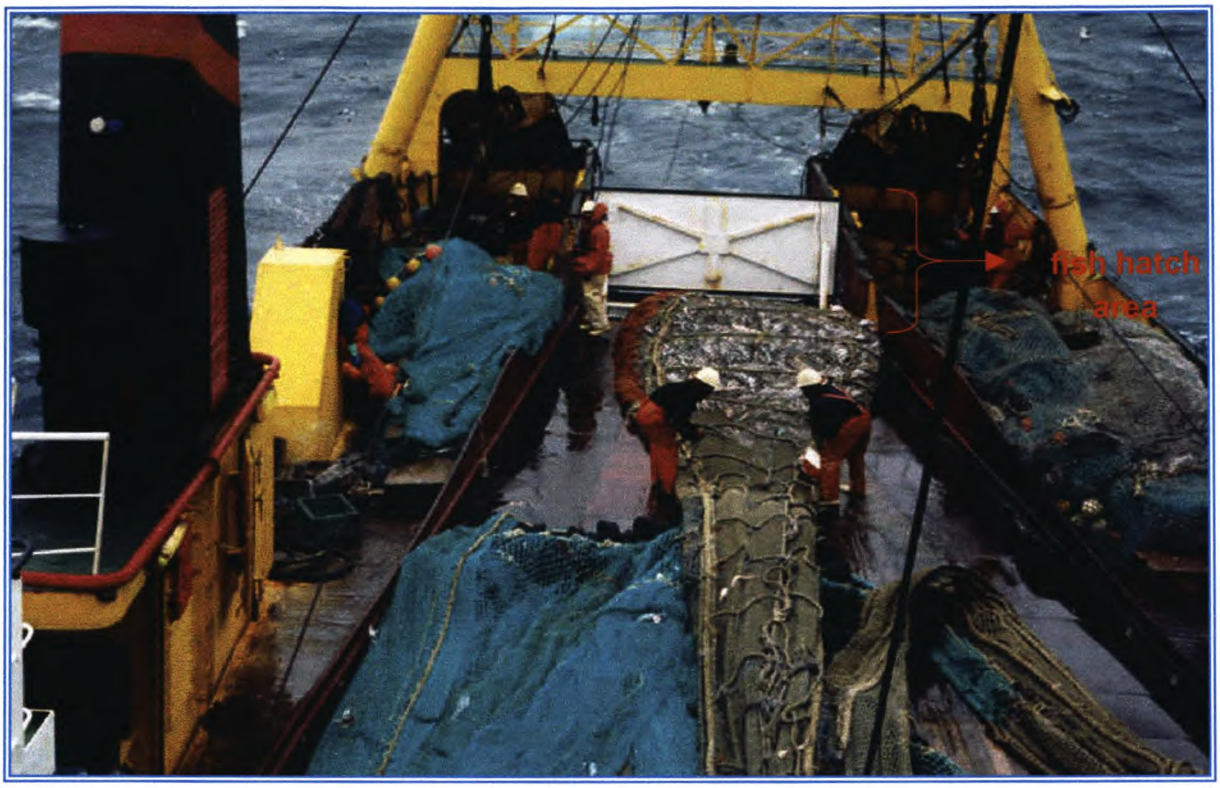


Figure 2. The rear end of trawl boat where the fish hatch area is situated.

Figure 3. Diverse species of bycatch trawled in addition to target species.

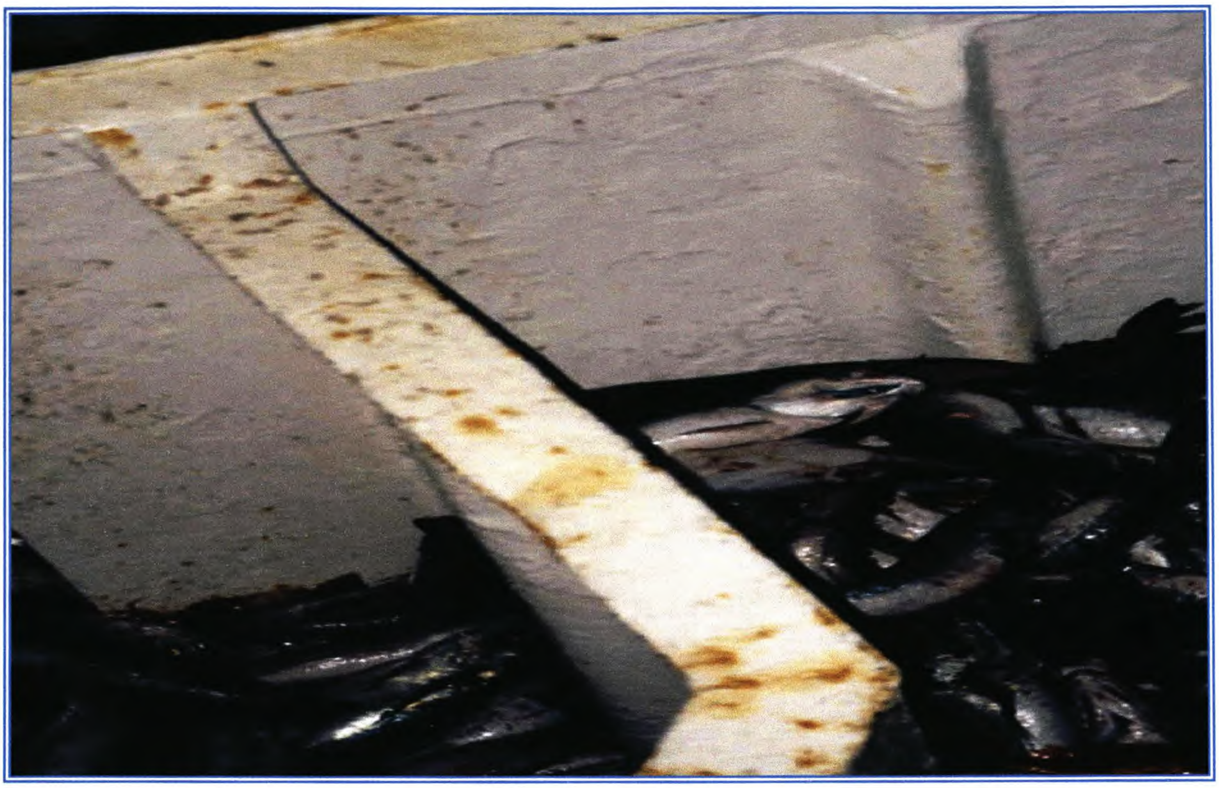


Figure 4. Fish hatch area showing two stock-up ponds.

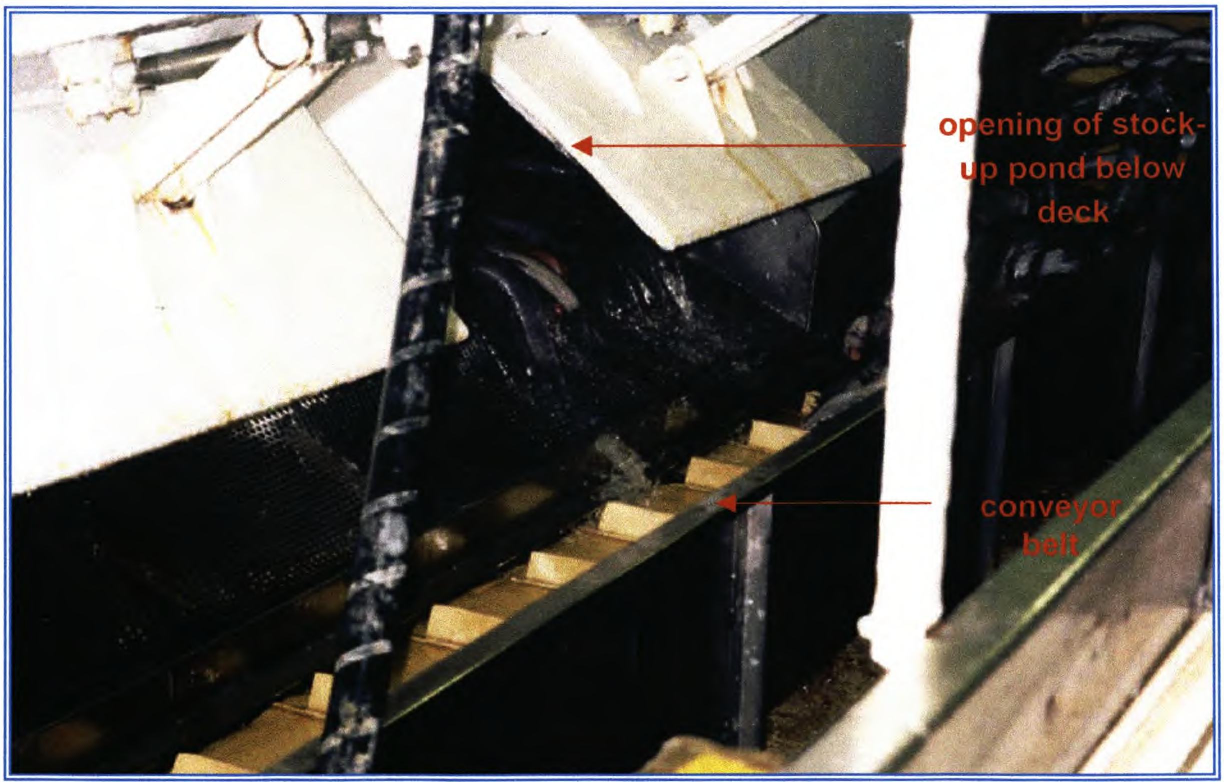


Figure 5. Stock-up pond has separate opening onto conveyor belt.

Figure 6. Separating area where bycatch is removed from Cape hake.

Figure 7. Conveyor belt passing each of the three onboard processing lines.

Onboard processing procedure

Perfect Quality hake (PQ hake)

Perfect Quality (PQ) hake is normally harvested only on the last three days of a single turnaround period (*ca.* 5 tonnes). Figure 7 shows the PQ processing line, which is also used for the processing of certain bycatch species when not in use. The PQ hake is first gutted by hand once it enters this processing line (no. 4a in Figure 1 & Figure 8), after which it gets dumped into a wash pond (no. 5a in Figure 8). The gut obtained from this process, except the roe, which is always retained and sold at R13 per kilogram after landing, gets dumped into the ocean via a shute system (Figure 7).

After the PQ hake is washed it is moved via a conveyor belt to a chill tank (no. 9a in Figures 1 & Figures 9 & 10). There are four such chill tanks, each for a specific category of processed hake. These chill tanks, contain chilled sea water at temperatures of *ca.* 6°C and *ca.* 3°C on a busy and not so busy day, respectively. Certain species of bycatch is processed in a similar manner as the PQ hake and only on certain occasions, deheading of the bycatch takes place. The hake is lowered manually into the fish room (10) only once all four chill tanks have been filled to capacity. Once the PQ hake has been lowered into the fish room it is packed into plastic bins in alternating layers with ice flakes. Prior to packing the PQ hake into plastic bins, the temperature of the PQ hake is recorded, and should ideally be *ca.* 3°C. The temperature of the fish room is maintained at *ca.* 1°C where the packed PQ hake remains until landing. The maximum storage capacity of the fish room is 69-70 tonnes (*ca.* 3000 plastic bins) of primary processed hake.

Small Headed & Gutted hake (Small H & G hake)

The second processing line is the small Headed & Gutted hake (Figure 7) processing line. The small hake is placed in between the grooves of a piano belt (no. 6 in Figure 1 & Figure 11), and is deheaded by means of its smooth blade. Deheading consists of severing the head behind the pectoral fins. The heads are dumped into the ocean via a shute system (8) and the deheaded hake is gutted by hand (4b) and the gut, apart from the roe, which is retained, is also dumped into the ocean via the shute system.

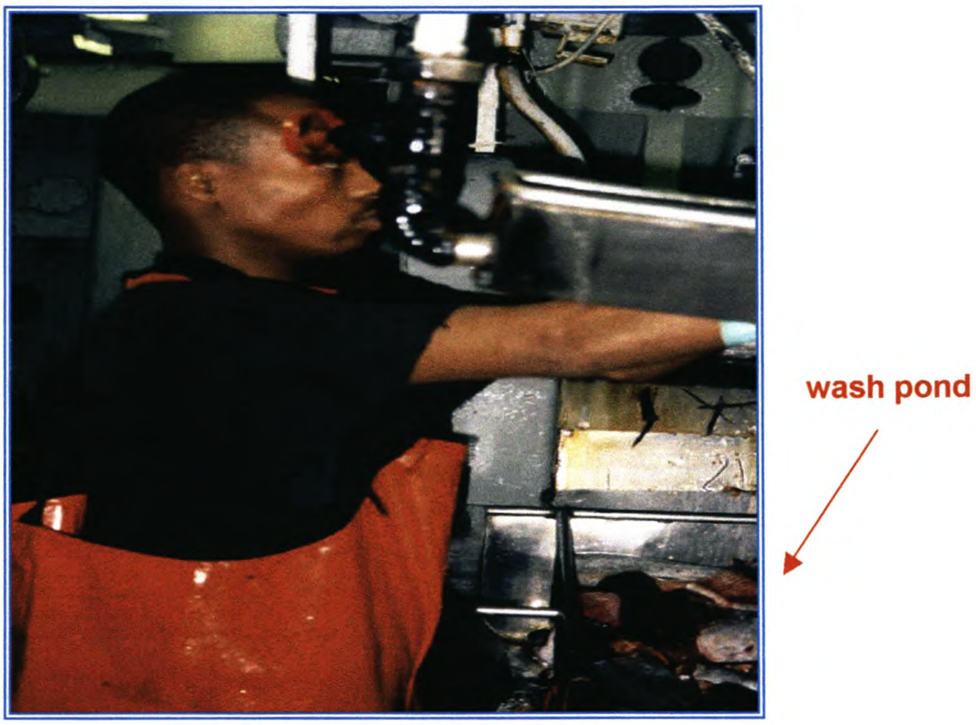


Figure 8. Crew member checks that all H & G hake are properly deheaded and gutted before rinsing.

Figure 9. Chill tank which maintains processed hake at *ca.* 3°C.

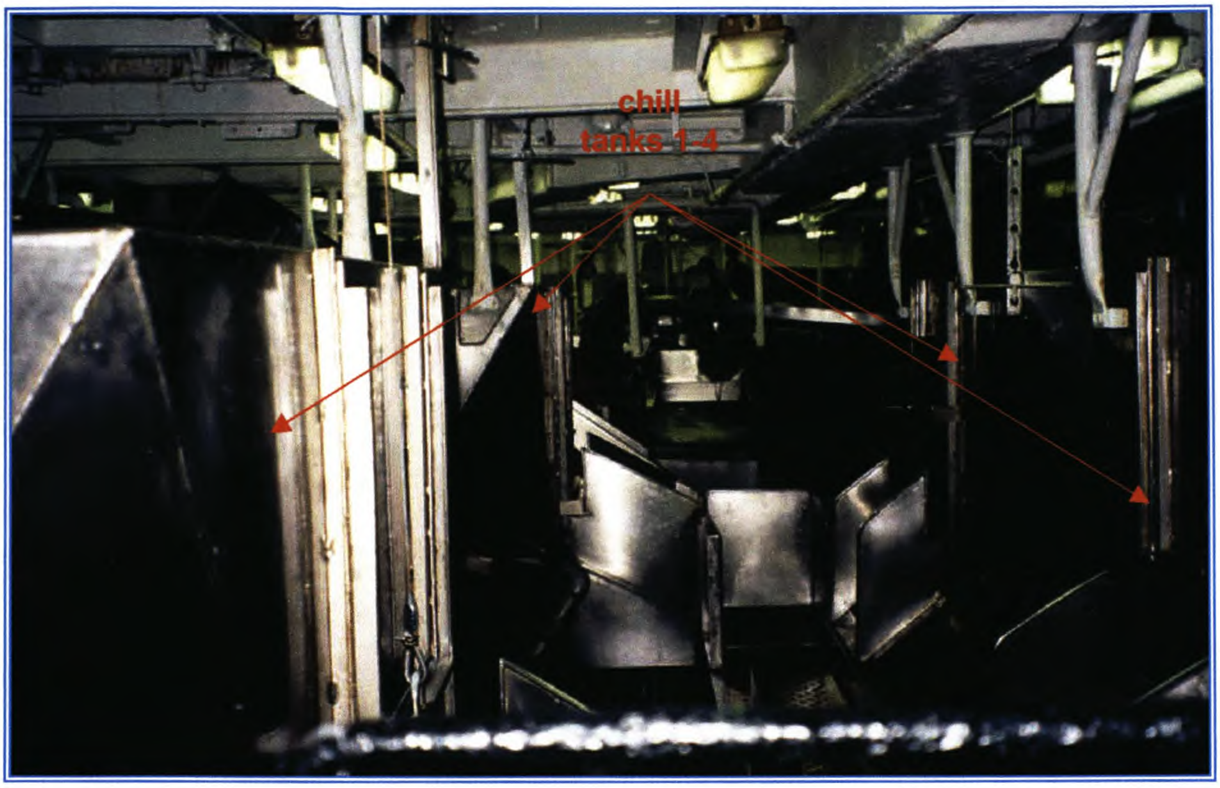


Figure 10. The four chill tanks each holding a specific type of processed hake.

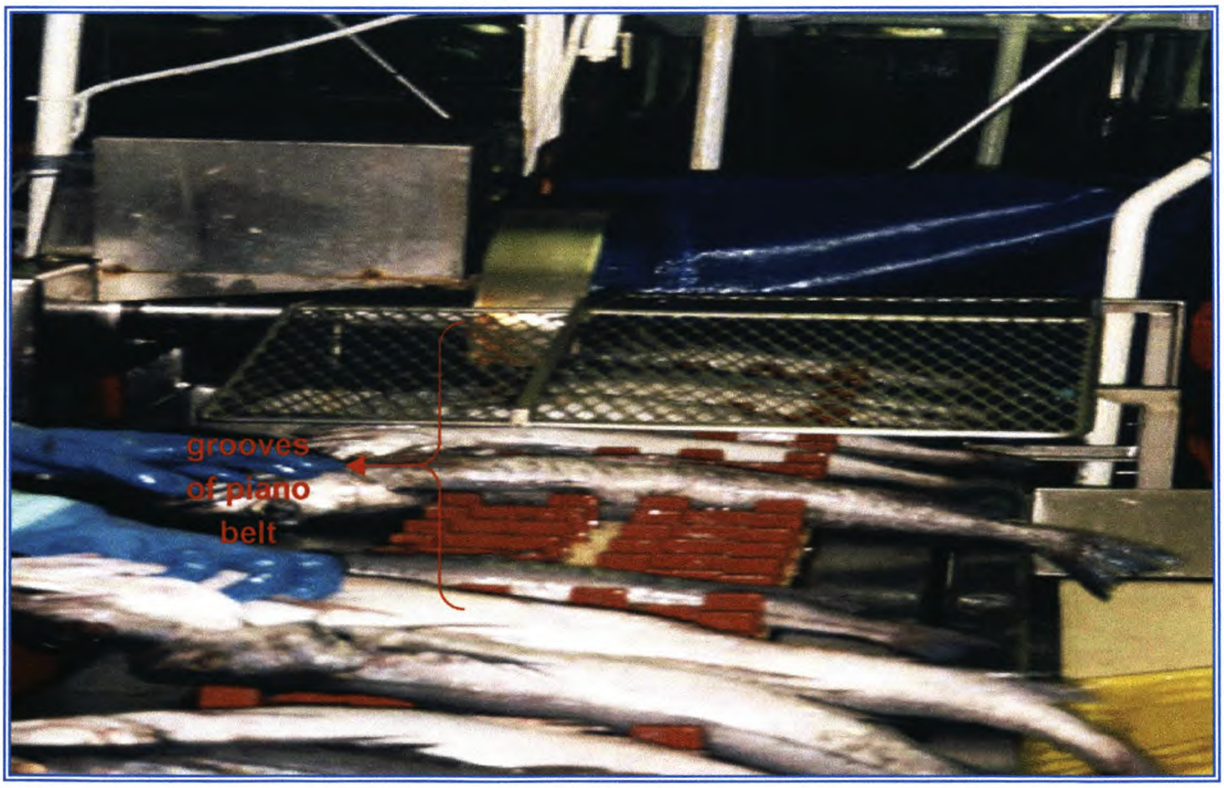


Figure 11. Grooved piano belt for small hake, deheading hake with a smooth blade.

The small H & G hake is then taken via another shute system to a wash pond (5b). The rest of the procedure for processing small H & G hake from this point until landing is the same as that of the PQ hake.

Medium and large Headed & Gutted hake (Medium H & G hake)

The medium and the large H & G hake are processed on the same processing line. Figure 12 shows how both medium and large hake are deheaded by means of a Baader machine (no. 7 in Figure 1, Figure 12), where a lever presses the body of the hake down to ensure that the hake does not move around during the deheading process and prevents unwanted skew irregular cuts. The hake heads are then dumped into the ocean via a shute system. The deheaded hake is then gutted by hand (4c) and the gut, except the roe, is dumped into the ocean. The large H & G hake is then taken via a shute system to the same wash pond (5b) as that of the small H & G hake whereas the medium H & G hake is washed in its own separate wash ponds (5c & d). The procedure followed by both medium and large H & G hake at the point of leaving the wash pond until landing, is the same as that of both PQ and small H & G hake.

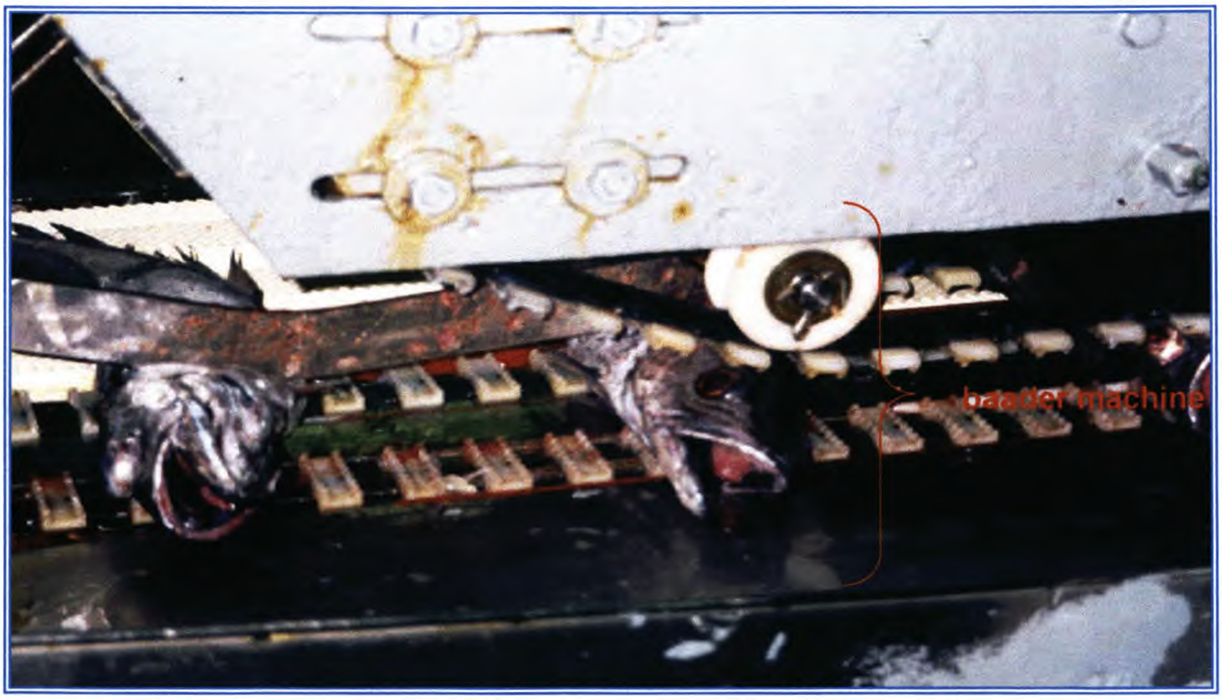


Figure 12. Baader machine with lever for medium and large hake, deheading hake with a smooth blade.

Discussion

Government incentives, based on a fixed price per kilogram for either bycatch or hake-waste landed, should be created for the landing and further processing of both bycatch and hake-waste harvested. Secondary processing of the bycatch and hake-waste landed could either be carried out by the existing commercial fishing industry or by creating an industry specialising in bycatch and hake-waste processing. It will be important to keep the price fixed for all species since species based incentives would create bias within the fishing industry towards landing specific species, consequently resulting in skewed data capturing by marine scientists. A year round market should also be created for these diverse species of bycatch and hake-waste to ensure profitability and economic feasibility. Government should also invest more money into marine research, particularly bycatch and hake-waste, by both independent research companies and tertiary institutions to determine the impact the current hake harvesting procedure has on the hake population itself as well as the diverse bycatch species also affected during this harvesting procedure. This would then enable the fishing industry to increase their harvesting efficiency as well as allowing them to make informed decisions concerning the harvesting of a specific fish species.

The current hake harvesting procedure should allow for at least two openings from each stock-up pond within the fish hatch area. This would then alleviate congestion, which would decrease the amount of bruised and damaged hake. Another suggestion would be to retain all hake heads and bycatch, the extent of which would be determined by the harvesting efficiency of the target species during a specific turnaround period. The bycatch species harvested would be processed on a single line with no deheading taking place, only gutting. All diverse species of bycatch could be washed in the same wash pond and chilled in the same chill tank before being packed into alternating layers of crushed ice in plastic bins until landing. The large and small hake heads obtained during processing could be retained and washed in the same wash pond and chilled in the same chill tank whereas the medium hake heads would have its own separate wash pond and chill tank. The hake heads could then be packed into alternating layers of crushed ice in plastic bins and stored in the fish room until landing.

Morphological measurements

Materials and methods

Sampling procedure of hake-waste

The sampling procedure was cumulative starting from drag one over the entire turnaround period of six days. The possibility existed that not all samples would be collected from intermittent drags. In the early phase of each boat trip, the selection of hake samples was random, but nearing the end of each boat trip specific hake in certain categories was selected to ensure representative samples in all categories. After each trawl a plastic bin was filled with different size whole hake (small, medium and large hake, respectively). The various size hake was then categorised into four categories according to the total length of the hake, i.e. category 1 (30 - 46 cm), category 2 (47 - 63 cm), category 3 (64 - 80 cm) and category 4 (>80 cm), respectively. A pre-marked wooden bench was used to categorise the various size hake into its respective categories and these hake were stored in marked plastic bins filled with ice flakes. Category 1 hake was worked first, followed by categories 2 and 3 and finally category 4 (each hake was worked fully before continuing with the next hake).

The hake was first measured with a measuring tape attached to the pre-marked wooden bench to determine the total length of the whole hake (from the hake head snout to the tip of the forked tail). Next, the whole hake was weighed on a mechanical platform scale to determine its mass. The hake was deheaded by severing it behind the pectoral fins using a sharp knife with a smooth blade. The gut was removed by inserting one's hand into its abdominal cavity and carrying out a 'rip out' action. The hake head as well as the H & G hake were weighed separately on either a 2.5 or 15 kilogram mechanical platform scale, depending on the accuracy required, to determine their respective masses. All the readings taken from the mechanical platform scale were an estimated mean of two readings taken because of the constant swaying of the wet-fish trawl boat. The H & G hake was then returned to the processing line.

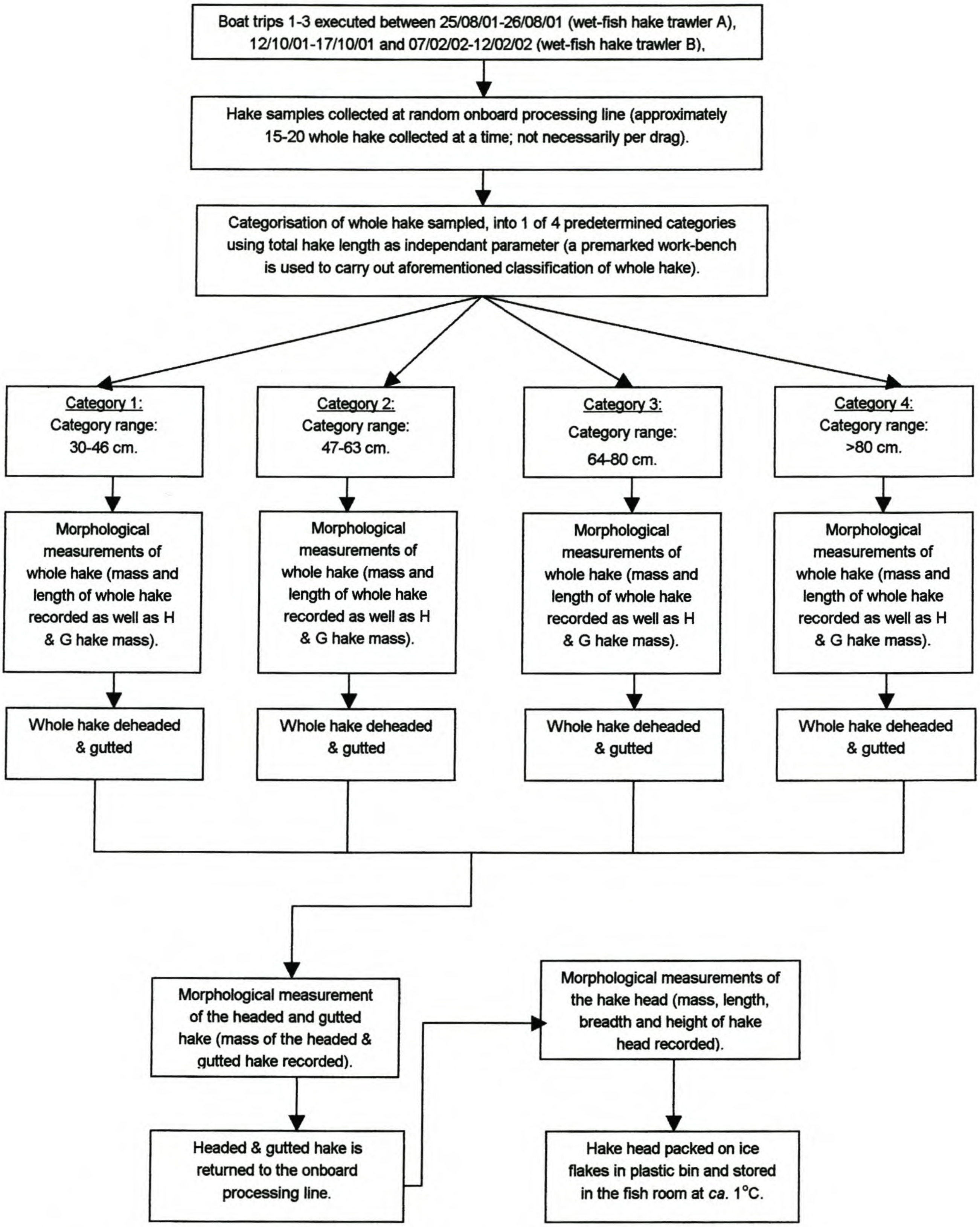
The hake head length, breadth and height were measured after which the head was placed into one of the four appropriately marked plastic bins containing ice flakes. All these steps were repeated until all the whole hake was processed and then stored below the hake processing area in the fish room (*ca.* 1°C). Figure 13 gives a functional flow diagram of the steps executed for each boat trip to ensure that the objectives were successfully achieved. For the respective boat trip a prediction model was constructed, for each dependant morphological variable (whole hake mass, H & G hake mass, hake head mass, length, breadth and height), with the use of the exponential equation:

$$y=e^{(a_0+a_1)\,(\text{whole hake length (cm)})}$$

Both the Mean Square Error (MSE) and Pearson's correlation coefficient (r) were calculated to determine the predictive ability of the prediction model.

Statistical analysis

In constructing prediction models, curve fittings of all the data points of each of the three respective boat trips were compiled using non-linear regression curves. Prediction models were constructed using 80% of the original data recorded (training set) whereas the remaining 20% (test set) was used to determine the predictive ability of the respective prediction model. For each of the three boat trips the sample size investigated for the morphological parameters were 115, 185 and 572 hake, respectively. To determine the differences between the a_0 and a_1 coefficient values for each respective prediction model (whole hake mass, H & G hake mass, hake head mass, length, breadth and height) 95% confidence intervals for the coefficients were inspected between boat trips.



Boat trips 1-3 executed between 25/08/01-26/08/01 (wet-fish hake trawler A), 12/10/01-17/10/01 and 07/02/02-12/02/02 (wet-fish hake trawler B).

Hake samples collected at random onboard processing line (approximately 15-20 whole hake collected at a time; not necessarily per drag).

Categorisation of whole hake sampled, into 1 of 4 predetermined categories using total hake length as independant parameter (a premarked work-bench is used to carry out aforementioned classification of whole hake).

Category 1: Category range: 30-46 cm.

Category 2: Category range: 47-63 cm.

Category 3: Category range: 64-80 cm.

Category 4: Category range: >80 cm.

Morphological measurements of whole hake (mass and length of whole hake recorded as well as H & G hake mass).

Whole hake deheaded & gutted

Morphological measurement of the headed and gutted hake (mass of the headed & gutted hake recorded).

Headed & gutted hake is returned to the onboard processing line.

Morphological measurements of the hake head (mass, length, breadth and height of hake head recorded).

Hake head packed on ice flakes in plastic bin and stored in the fish room at *ca.* 1°C.

Figure 13. Flow diagram of onboard hake sampling procedure.

Results and discussion

Category 1 hake had a minimum length of 30 cm since small hake (i.e. < *ca.* 25 cm in total length) were not caught by the trawling gear, which is in agreement with the findings of Payne *et al.* (1987).

Detailed results of the seven morphological parameters (whole hake length, mass, H & G hake mass, hake head mass, length, breadth and height) for the three respective boat trips are given in Appendix 3 (Tables 1-4). Figures 14-31 depicts the prediction models for whole hake mass (Figures 14-16); H & G hake mass (Figures 17-19); hake head mass (Figures 20-22); hake head length (Figures 23-25); hake head breadth (Figures 26-28) and hake head height (Figures 29-31) vs. whole hake length for the three boat trips, respectively.

From Figures 14, 17, 20, 23, 26 and 29 it can be seen that for boat trip one the majority of the data were categorised within categories 1 (30 - 46 cm) and 2 (47 - 63 cm), the former category forming the bulk of data points recorded of these two categories. This was due to an unexpected shortened turnaround period of only two days. There is a district tendency in the second and third boat trips for the data points in categories 3 (64 - 80 cm) and 4 (>80 cm) to deviate more from the curve of the prediction model than that of categories 1 and 2 (Figures 15-16 and 18-19). This can be attributed to the fact that fewer data points were recorded in categories 3 and 4 and when investigating biological specimens one expects to find greater variance in the larger specimens.

Figures 15, 18, 21, 24, 27 and 30 show a clustering of data points in three areas in the prediction models of the second boat trip. The first cluster of data points occurs within category 1 and the second in the upper level and lower levels of categories 2 and 3, respectively. The third cluster of data points also occurred across two categories namely, the upper and lower levels of categories 3 and 4, respectively. This clustering of data points can be attributed to latitudinal stratification of the Cape hake population by age as suggested by Dark (1975), hence the stratification by size, which also increases the difficulty of representative sampling.

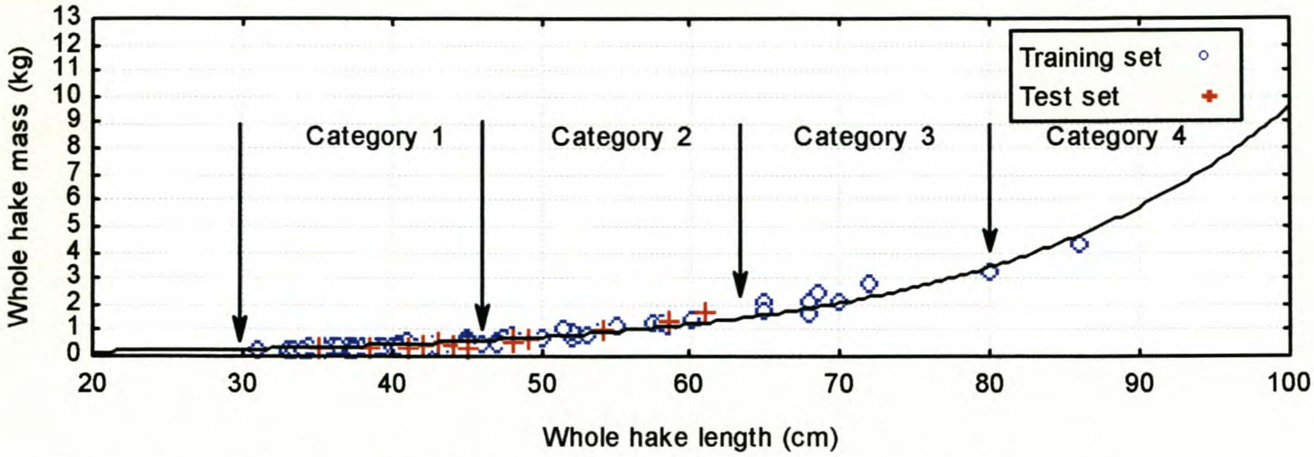


Figure 14. The whole hake mass (kg) prediction model for the first boat trip.

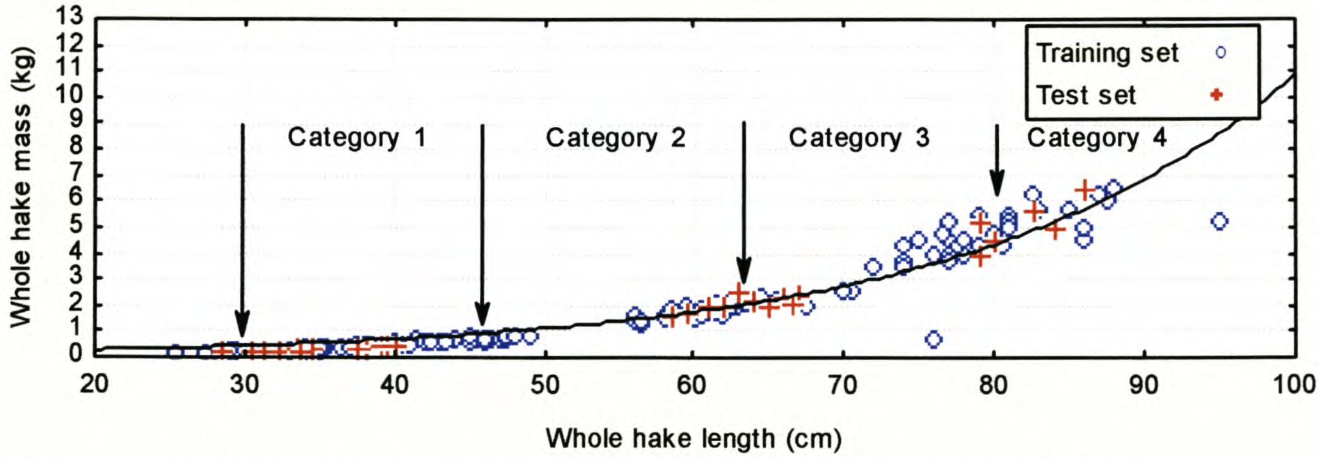


Figure 15. The whole hake mass (kg) prediction model for the second boat trip.

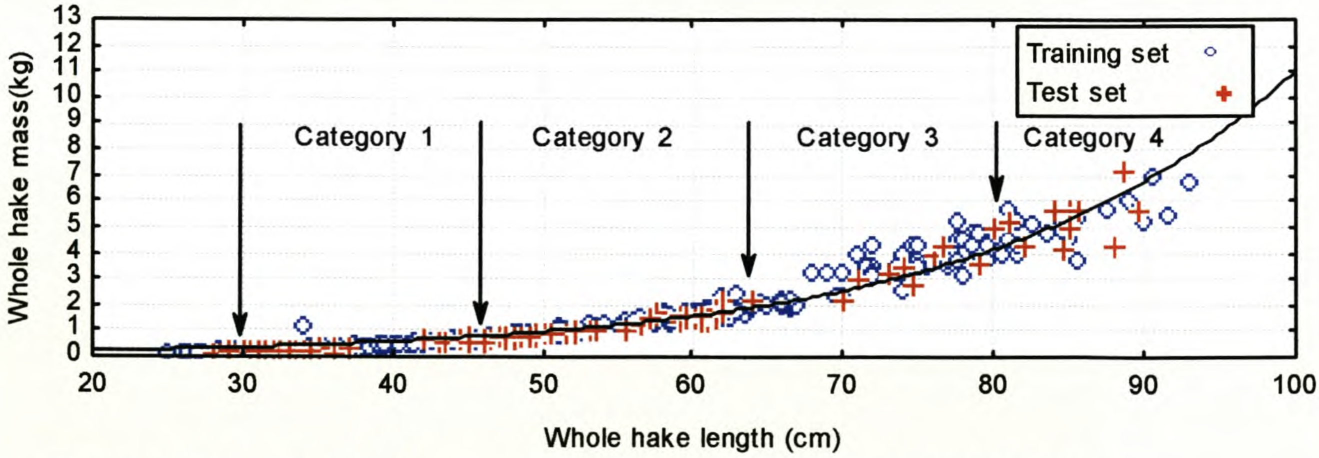


Figure 16. The whole hake mass (kg) prediction model for the third boat trip.

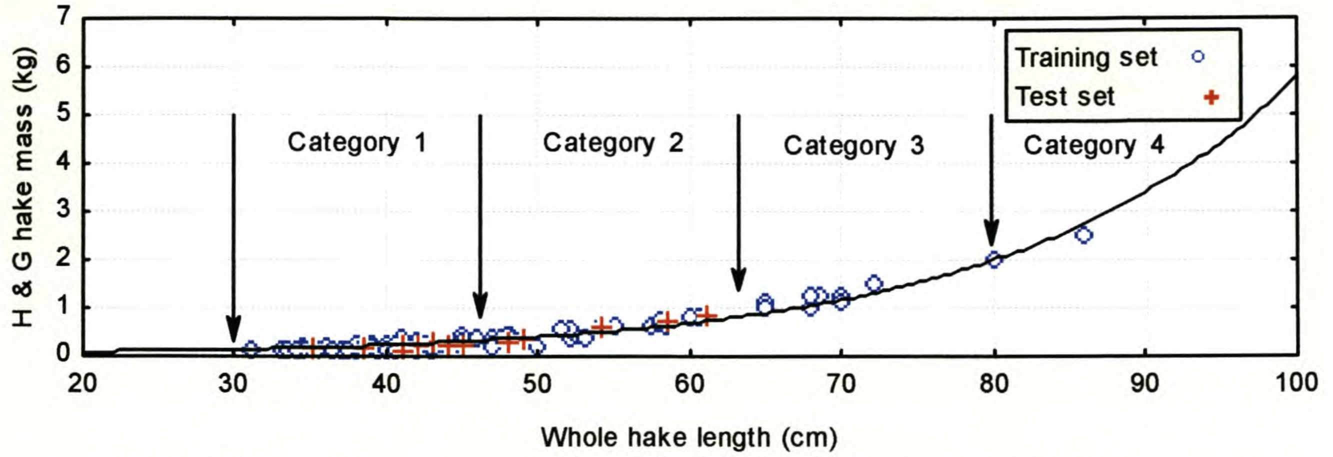


Figure 17. The H & G hake mass (kg) prediction model for the first boat trip.

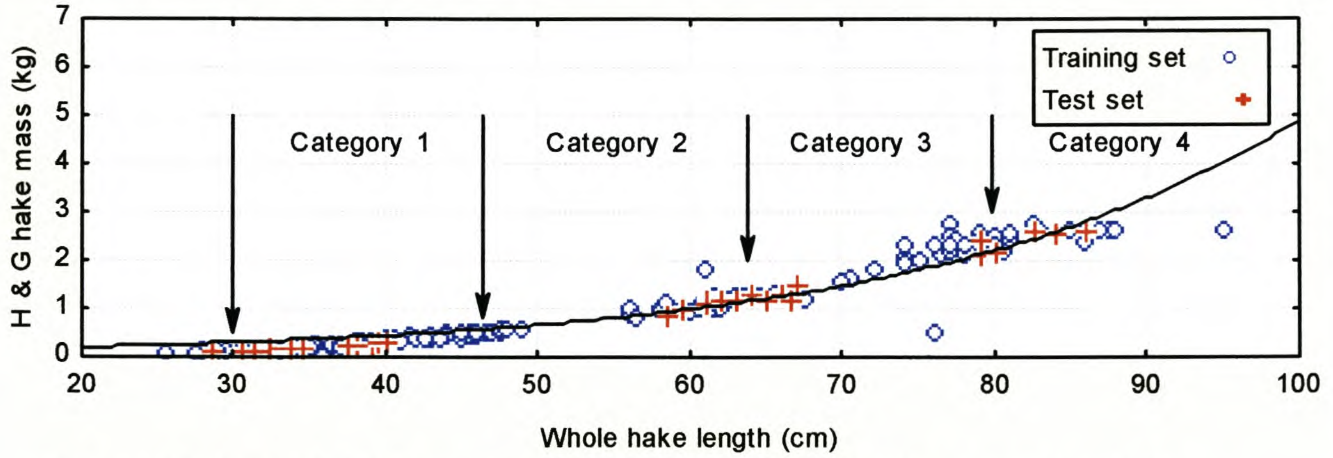


Figure 18. The H & G hake mass (kg) prediction model for the second boat trip.

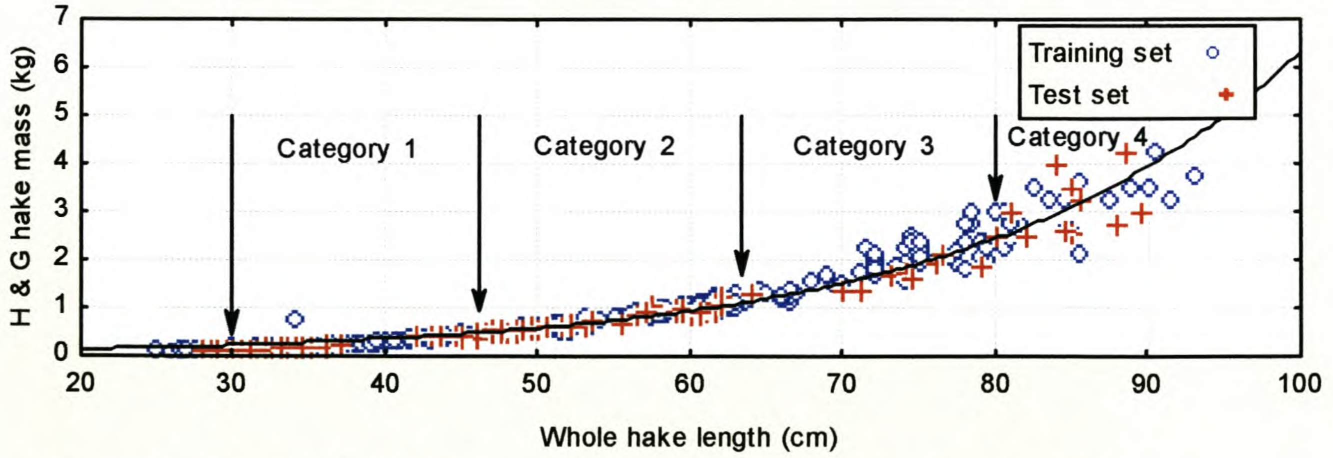


Figure 19. The H & G hake mass (kg) prediction model for the third boat trip.

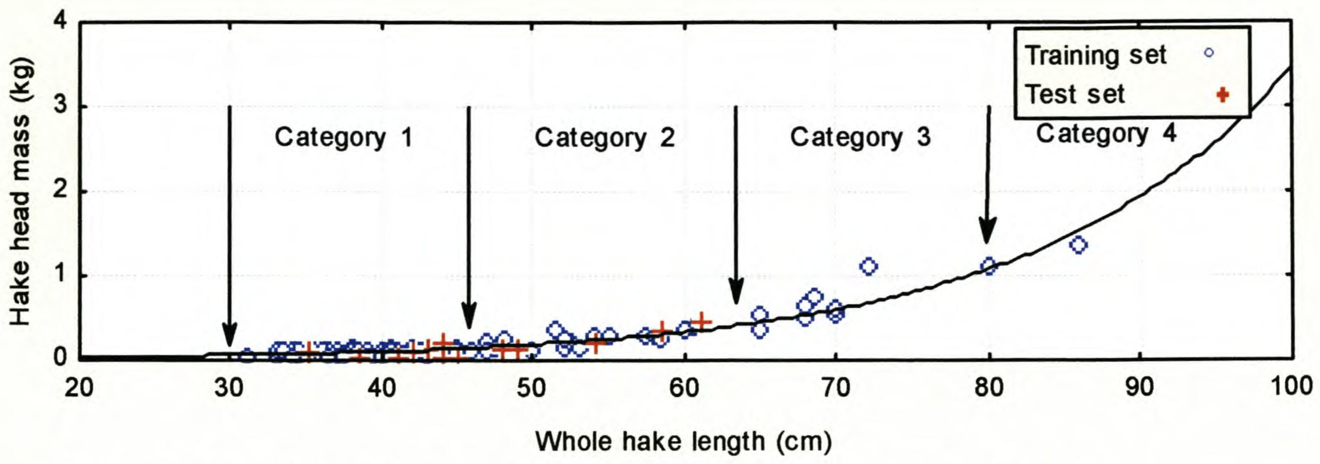


Figure 20. The hake head mass (kg) prediction model for the first boat trip.

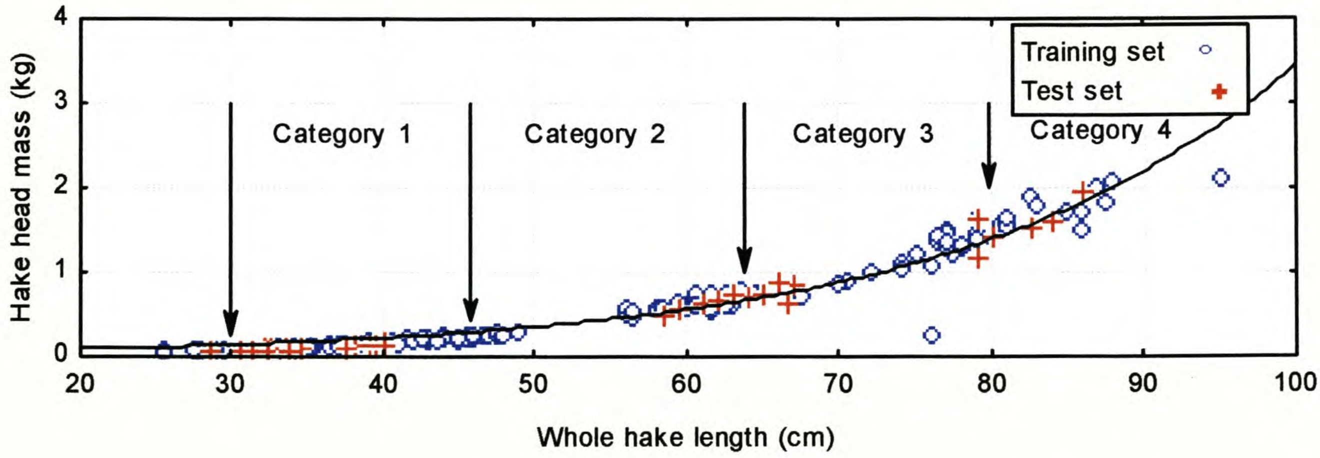


Figure 21. The hake head mass (kg) prediction model for the second boat trip.

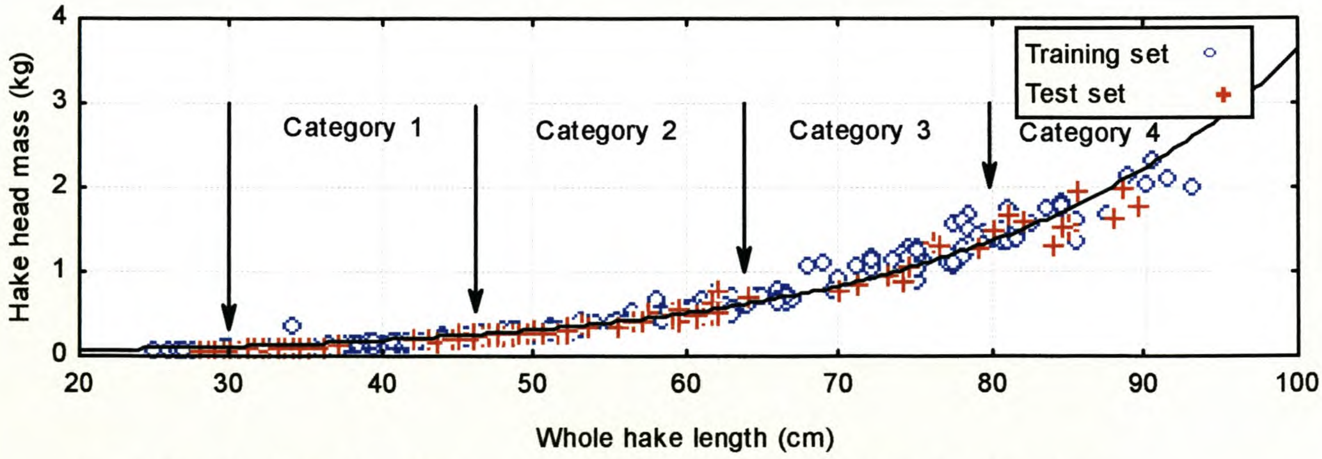


Figure 22. The hake head mass (kg) prediction model for the third boat trip.

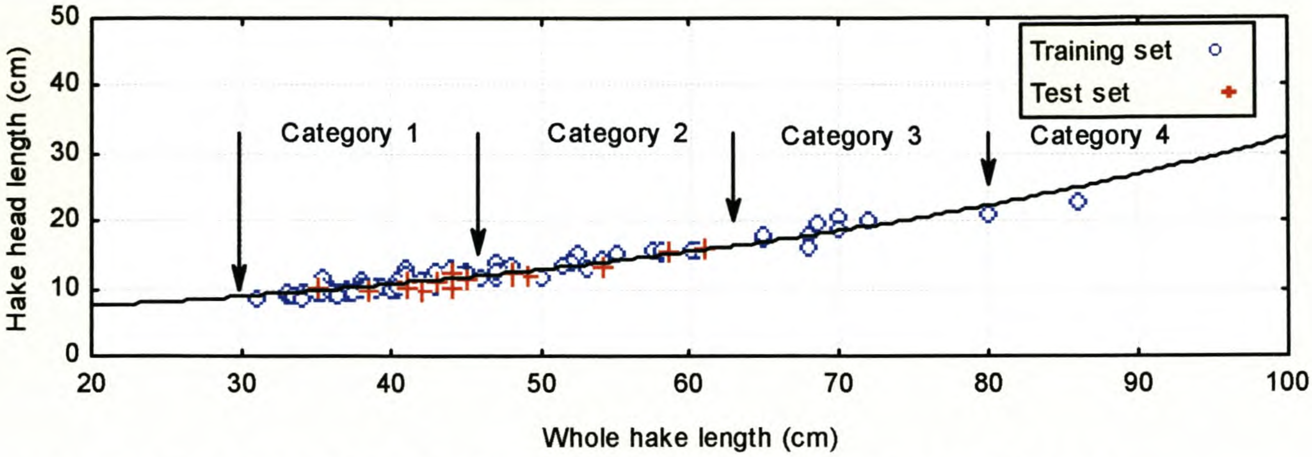


Figure 23. The hake head length (cm) prediction model for the first boat trip.

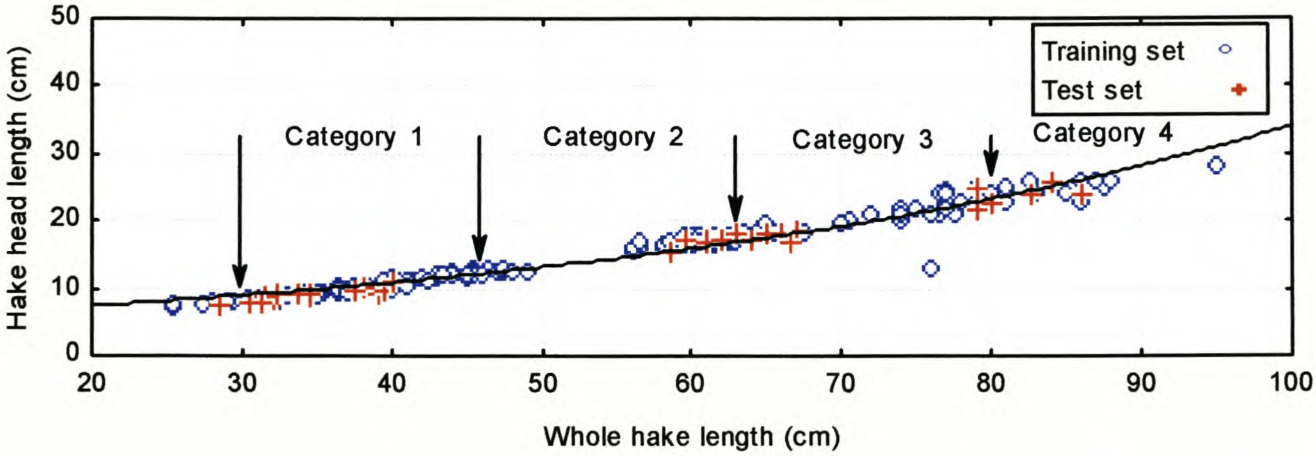


Figure 24. The hake head length (cm) prediction model for the second boat trip.

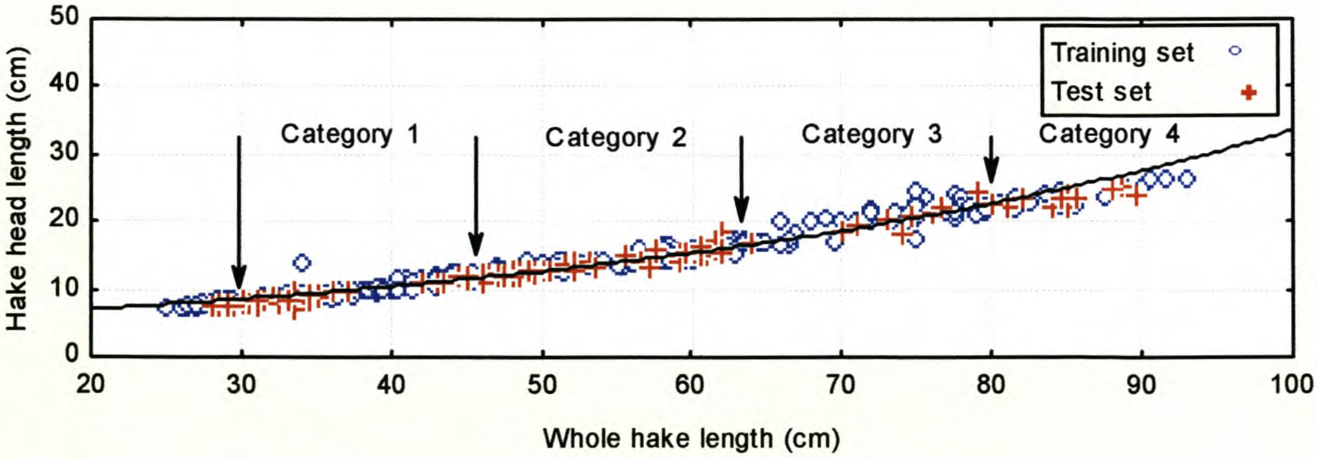


Figure 25. The hake head length (cm) prediction model for the third boat trip.

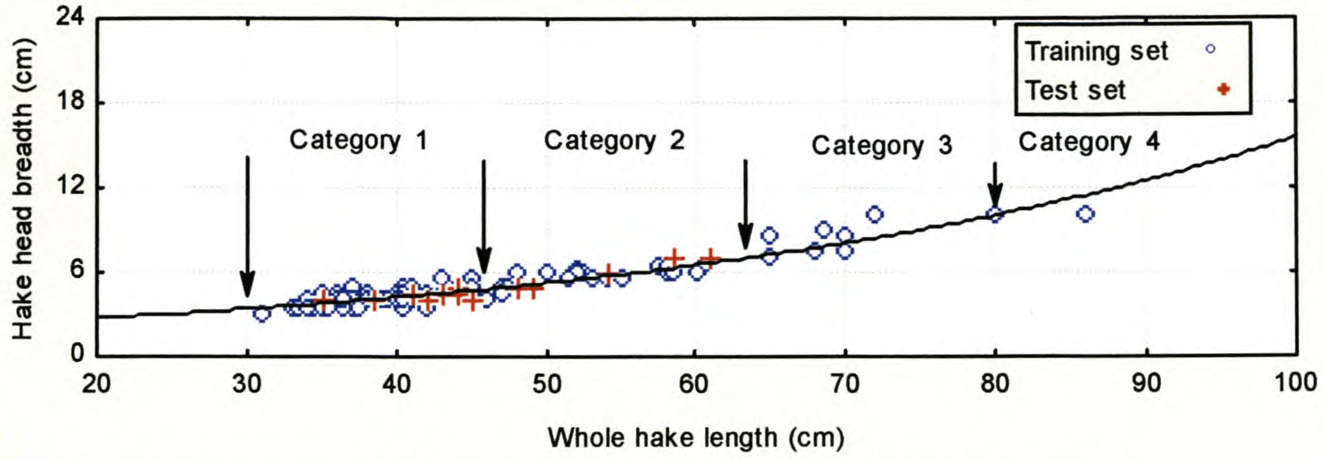


Figure 26. The hake head breadth (cm) prediction model for the first boat trip.

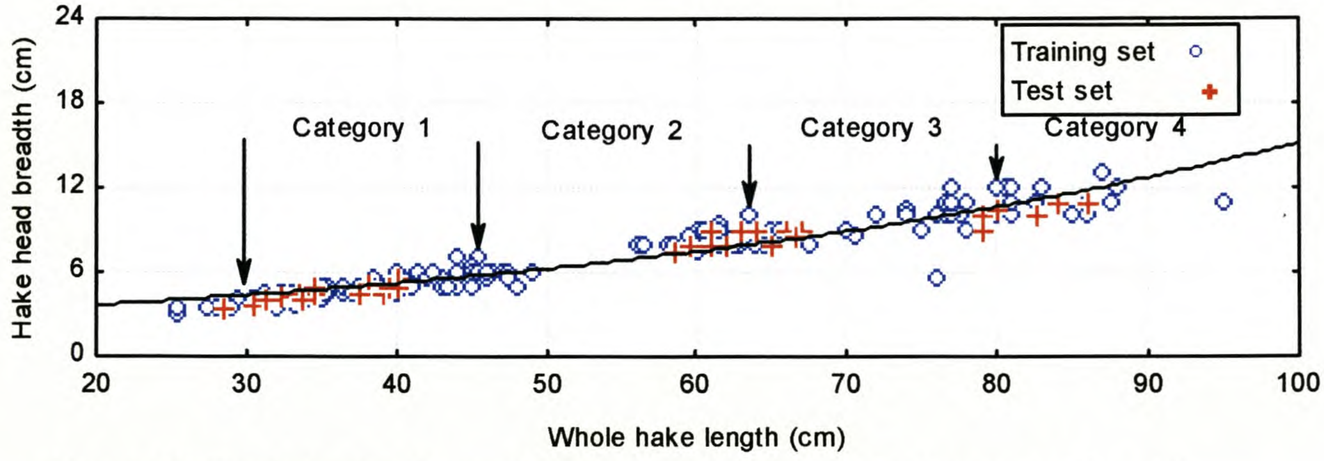


Figure 27. The hake head breadth (cm) prediction model for the second boat trip.

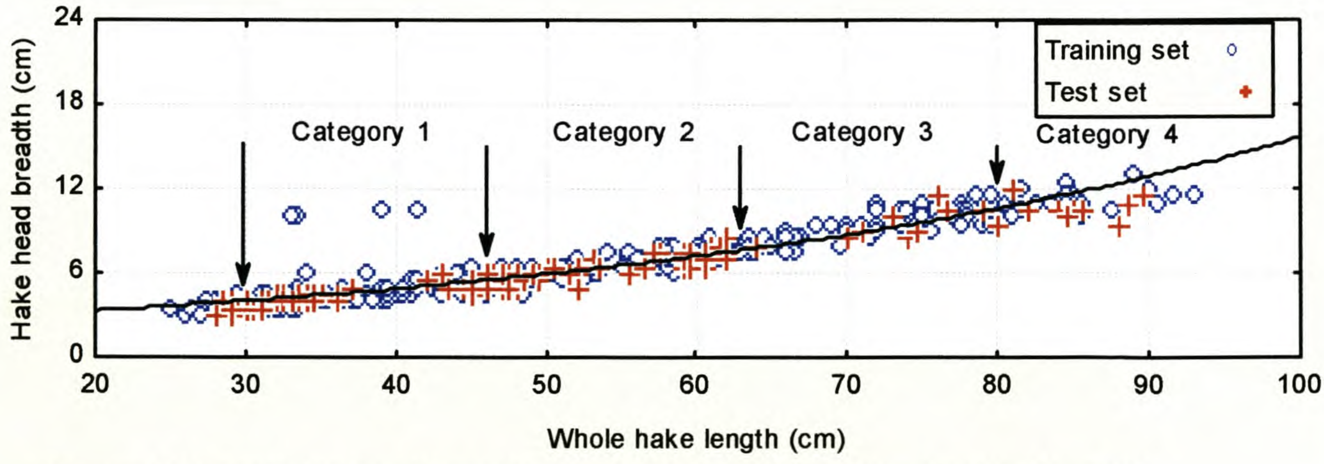


Figure 28. The hake head breadth (cm) prediction model for the third boat trip.

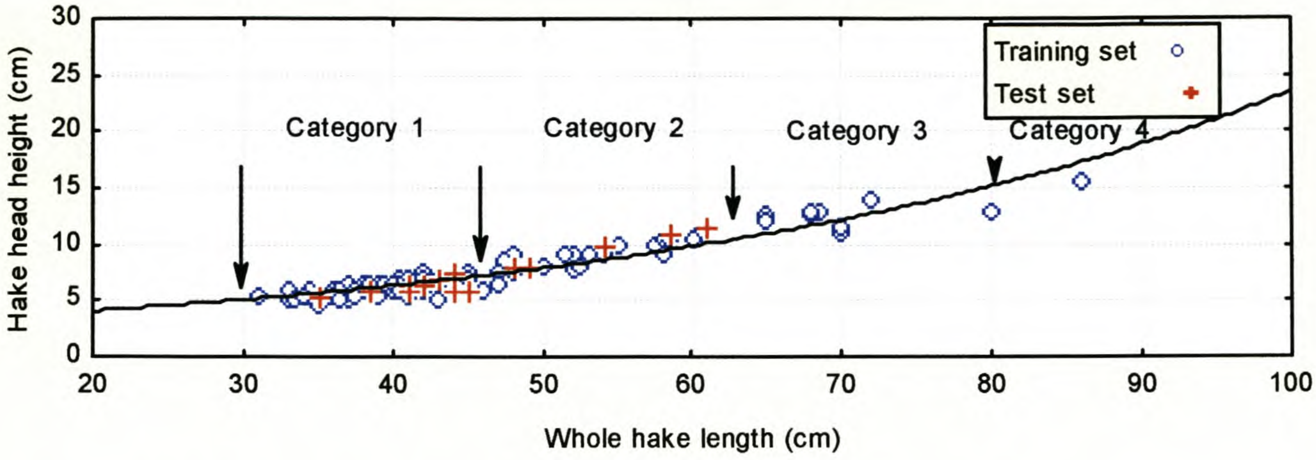


Figure 29. The hake head height (cm) prediction model for the first boat trip.

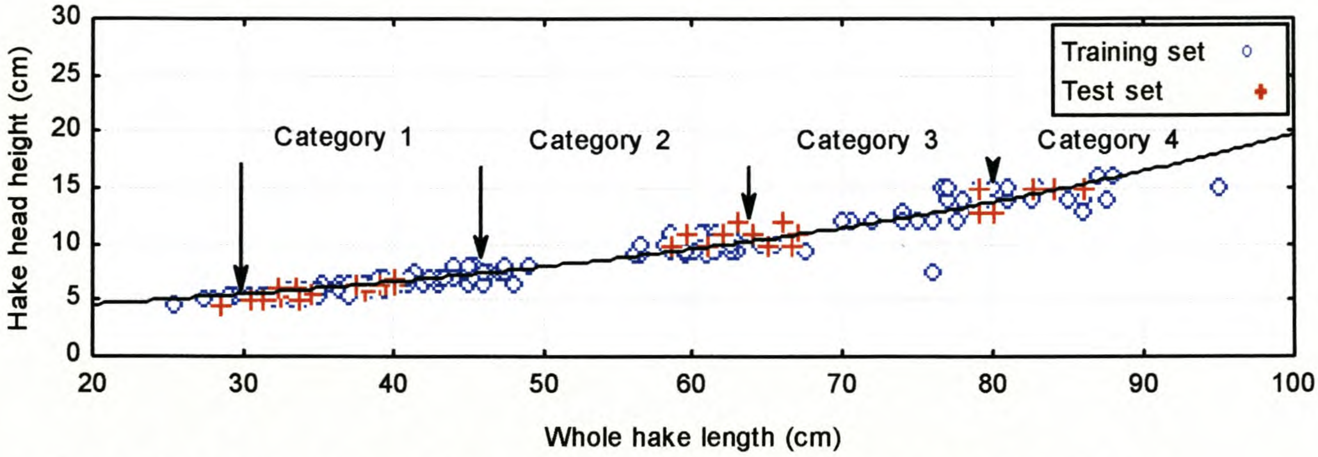


Figure 30. The hake head height (cm) prediction model for the second boat trip.

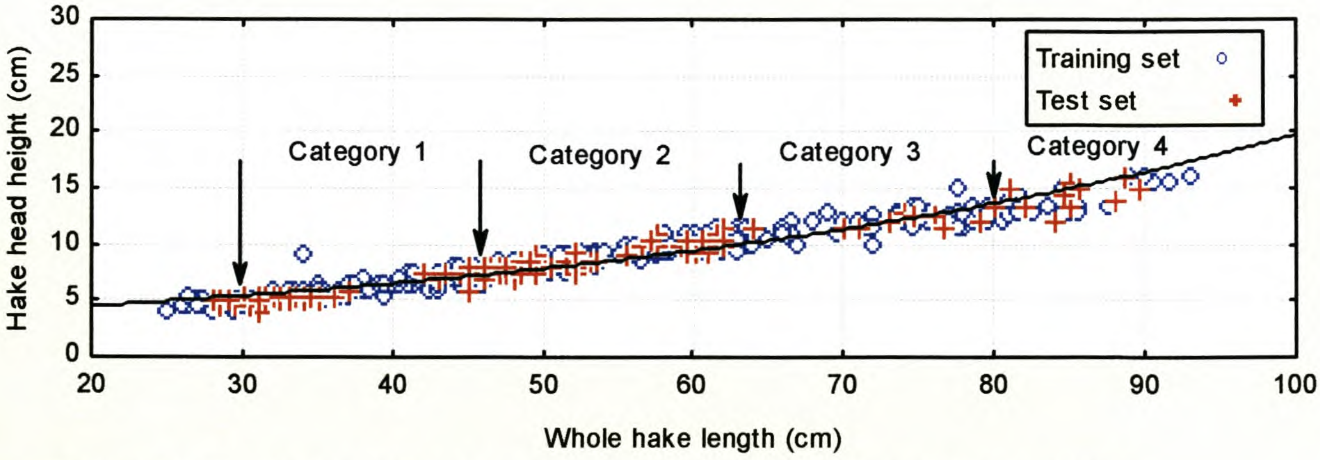


Figure 31. The hake head height (cm) prediction model for the third boat trip.

Figures 32-37 represents comparisons of the prediction models of the three boat trips for the whole hake mass, H & G hake mass, hake head mass, length, breadth and height. The models, for the three respective boat trips, to predict whole hake mass (Figures 14-16), H & G hake mass (Figures 17-19), hake head mass (Figures 20-22), hake head length (Figures 23-25), hake head breadth (Figures 26-28) and hake head height (Figures 29-31) from whole hake length have good predictive abilities indicated by the low Mean Square Error (MSE) values for the test sets and high Pearson's correlation coefficient (r) values as shown in Table 1.

Table 2 shows that there is no significant differences (confidence interval overlap) between the prediction equations of the second and third boat trips when comparing the a_0 and a_1 coefficients of the exponential equations, predicting whole hake mass, hake head mass, length, breadth and height. Significant differences ($p<0.01$) do, however, occur between boat trips two and three for the H & G hake mass prediction model as well for the hake head breadth prediction model (Table 1). It is clear that the coefficients for the second and third boat trips are closer together with that of the first boat trip somewhat removed. The exception was the hake head length model where neither of the three boat trips differed significantly ($p<0.01$) from each other. This is also reflected in Figure 35 where the similarity of the prediction models between the three boat trips is illustrated. From the aforementioned as well as the sample set sizes investigated per boat trip one can already conclude that the whole hake mass prediction models of the second and third boat trips would have more of a similar prediction curve due to different preferred fishing grounds by both the Skippers of wet-fish hake trawlers A and B. It was therefore decided to pool the data for the second and third boat trips together and fit a model on the combined data.

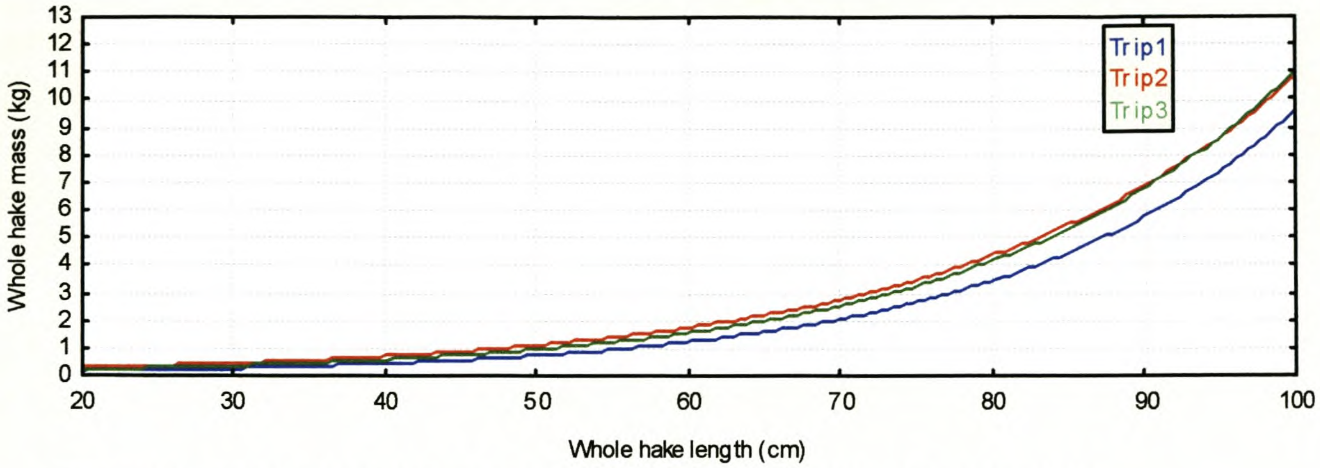


Figure 32. The whole hake mass (kg) prediction models for boat trips 1-3.

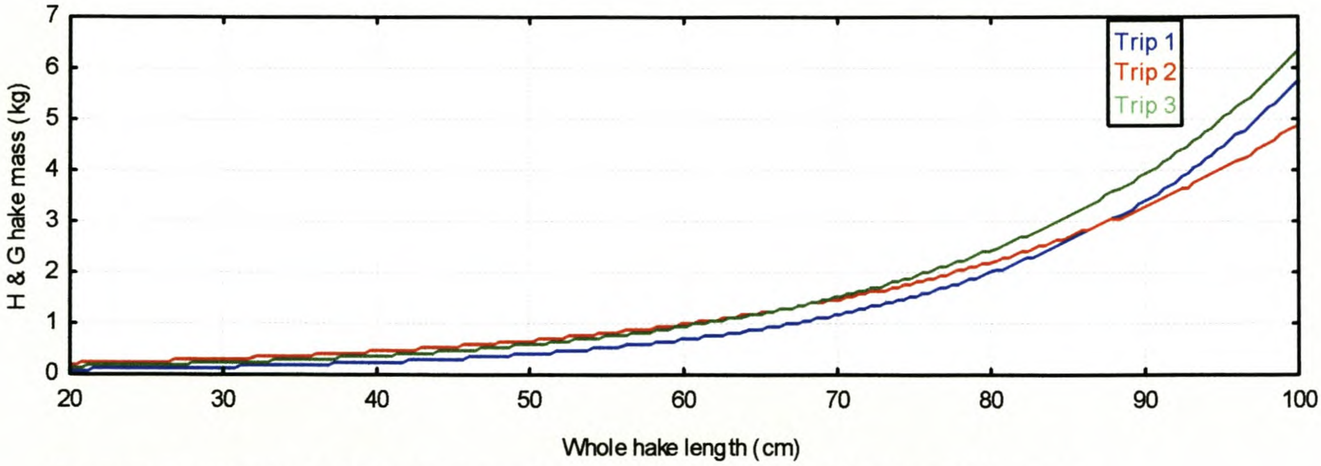


Figure 33. The H & G hake mass (kg) prediction model for boat trips 1-3.

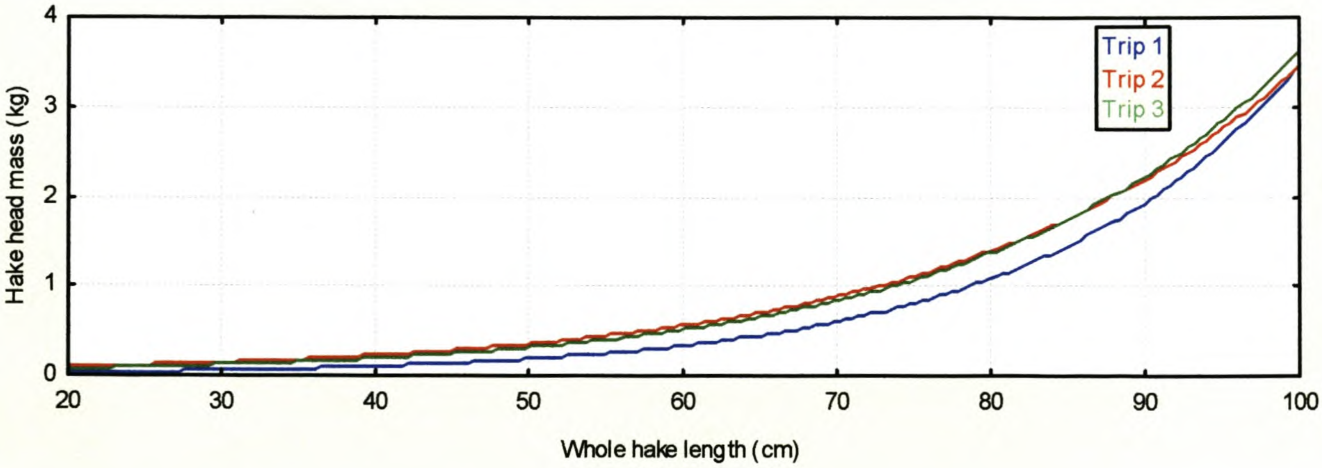


Figure 34. The hake head mass (kg) prediction model for boat trips 1-3.

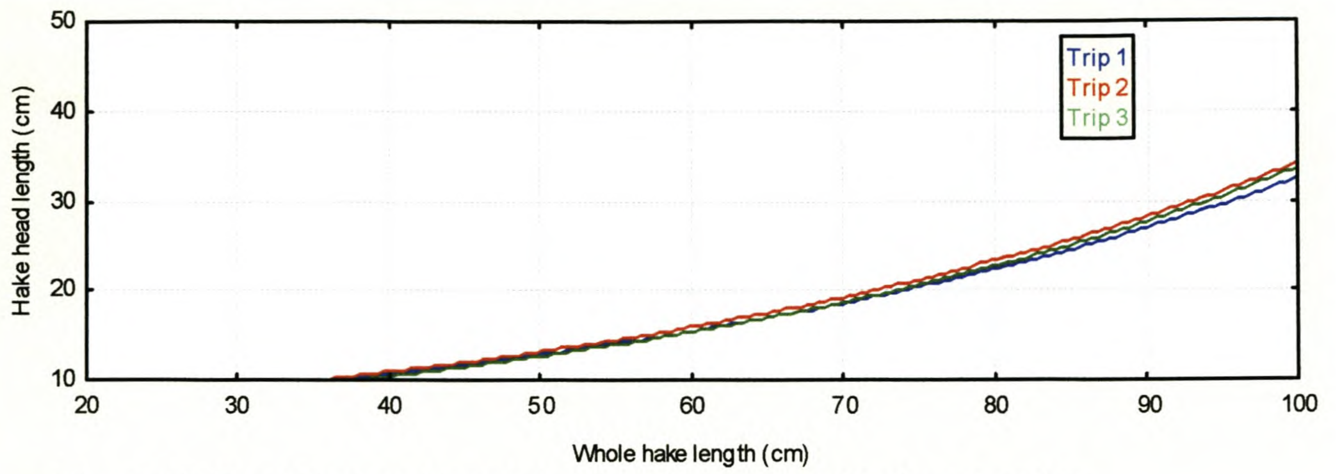


Figure 35. The hake head length (cm) prediction model for boat trips 1-3.

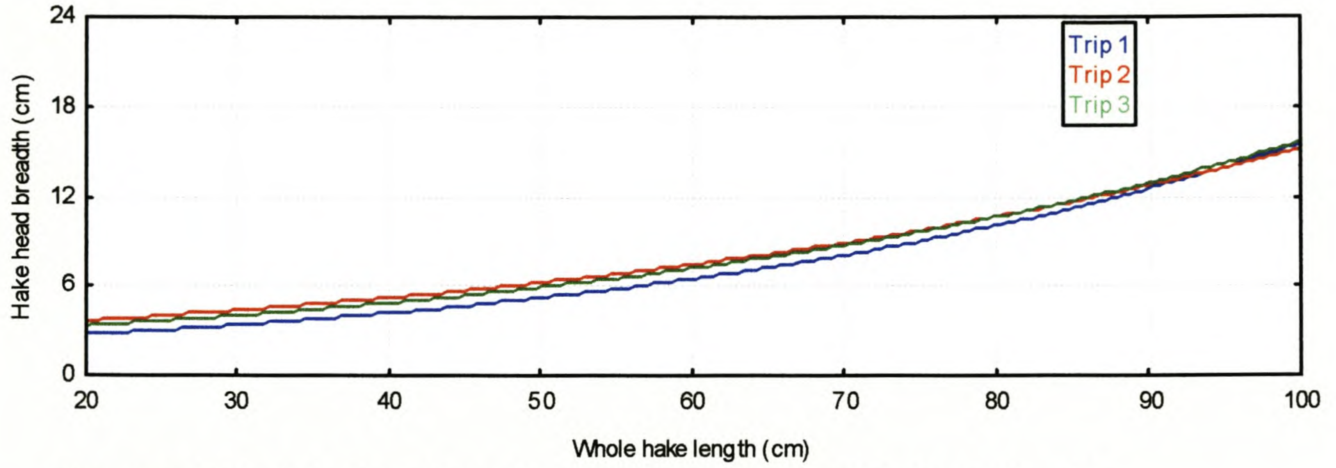


Figure 36. The hake head breadth (cm) prediction model for boat trips 1-3.

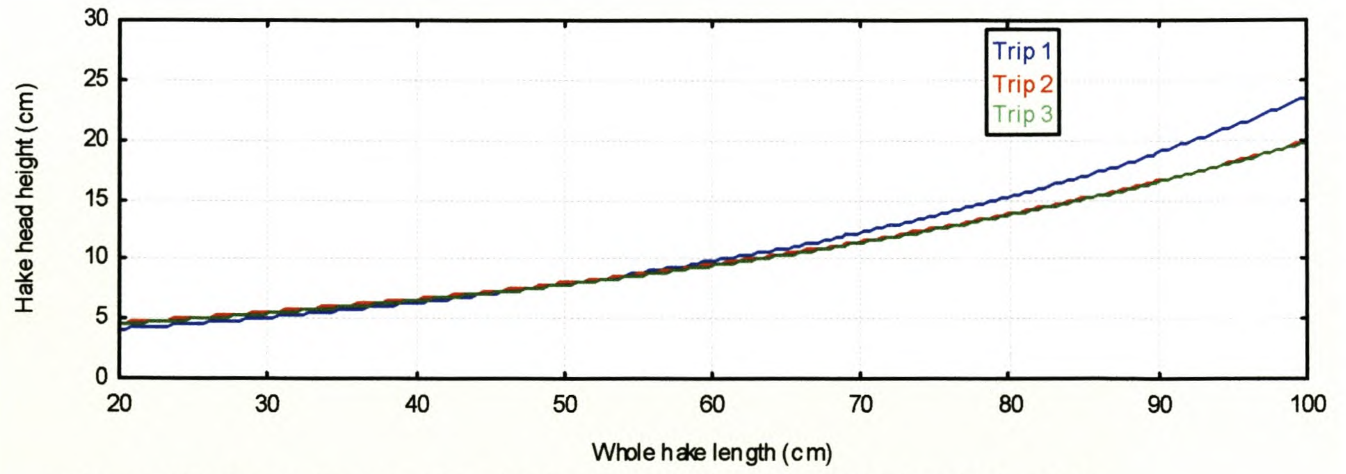


Figure 37. The hake head height (cm) prediction model for boat trips 1-3.

Table 1. The means square error (MSE), pearson's correlation coefficient (r) values for each of the six morphological parameters per boat trip.

Statistical analysis	Boat trip	Dependant morphological parameter Whole hake mass (kg)	H & G hake mass (kg)	Hake head mass (kg)	Hake head length (cm)	Hake head breadth (cm)	Hake head height (cm)
MSE	1	0.025	0.005	0.003	0.344	0.110	0.626
	2	0.117	0.021	0.008	0.907	0.398	0.533
	3	0.108	0.040	0.008	0.778	0.405	0.560
r	1	0.98	0.98	0.92	0.95	0.95	0.97
	2	0.99	0.99	0.99	0.99	0.97	0.98
	3	0.98	0.97	0.98	0.98	0.96	0.97

Table 2. The a_0 and a_1 coefficient values for each of the six morphological parameters investigated for each boat trip, respectively.

Morphological parameter	**Coefficient**					
	a_0			**a_1**		
	Boat trip			**Boat trip**		
	1	**2**	**3**	**1**	**2**	**3**
Whole hake mass (kg)	-2.848 a ± 0.134	-2.163 b ± 0.232	-2.471 b ± 0.092	0.051 a ± 0.002	0.045 b ± 0.003	0.049 b ± 0.00
H & G hake mass (kg)	-3.555 a ± 0.141	-2.397 b ± 0.197	-2.908 c ± 0.079	0.053 a ± 0.002	0.040 b ± 0.003	0.048 c ± 0.00
Hake head mass (kg)	-4.579 a ± 0.237	-3.305 b ± 0.182	-3.586 b ± 0.075	0.058 a ± 0.003	0.045 b ± 0.002	0.049 b ± 0.00
Hake head length (cm)	1.630 a ± 0.046	1.630 a ± 0.046	1.567 a ± 0.020	0.018 a ± 0.001	0.019 a ± 0.001	0.019 a ± 0.00
Hake head breadth (cm)	0.569 a ± 0.070	0.944 b ± 0.068	0.813 c ± 0.037	0.022 a ± 0.001	0.018 b ± 0.001	0.019 b ± 0.00
Hake head height (cm)	0.977 a ± 0.067	1.168 b ± 0.058	1.137 b ± 0.027	0.022 a ± 0.001	0.018 b ± 0.001	0.018 b ± 0.00

Pooling data within categories can mask any possible differences across different categories within a boat trip or differences between boat trips, which is in agreement with the findings of Pillar & Barange (1995). This therefore means that pooling the second and third boat trips for each of the six prediction models may be incorrect. Pooling data across geographical areas can, however, increase bias (accuracy); and variation (precision) in data can be reduced by increased sample size. If this is true, then the prediction models of boat trip 3, where the most hake heads were investigated (n=572), should be regarded as the most precise prediction models.

The strong correlation between prediction models for boat trips two and three can also be attributed to the fact that these samples were collected as the hake were entering their peak spawning season whereas boat trip 1 hake was sampled well into the secondary spawning season. Both species of Cape hake spawn throughout the year (Jones & Van Eck, 1967), however, the main spawning season usually occurs during spring extending from September to December/January (Botha, 1974; O'Toole, 1978; Hamukuaya, 1994). The decrease in feeding intensity during the spawning season (Roel & MacPherson, 1988) can also be a contributing factor towards why the prediction models of boat trips two and three are so close to each other as opposed to the respective prediction models of boat trip one.

The hake head length prediction models did not differ much between boat trips (Figure 35), as it is not affected by either hake sex, time of year when sampling is executed, spawning or sample set size. Figures 38-43 depict the pooled training and test set data of boat trips two and three for each respective prediction model and it can clearly be seen that there is a deviation of both training and test set data points from the mean prediction curve with an increase in size. This is particularly evident for categories 3 and 4. This increasing variance from category 3, can be attributed to a small sample size, which is in agreement with findings of Punt *et al*. (1992). Even though the category 3 and 4 section of each respective prediction model may be deemed imprecise due to the effects of small sample size, pooled data is nevertheless regarded as more precise (Punt *et al*., 1992). Random sample selection may have reduced any possible bias (Punt & Leslie, 1995), however, this led to certain category classes (categories 3 and 4) being poorly sampled.

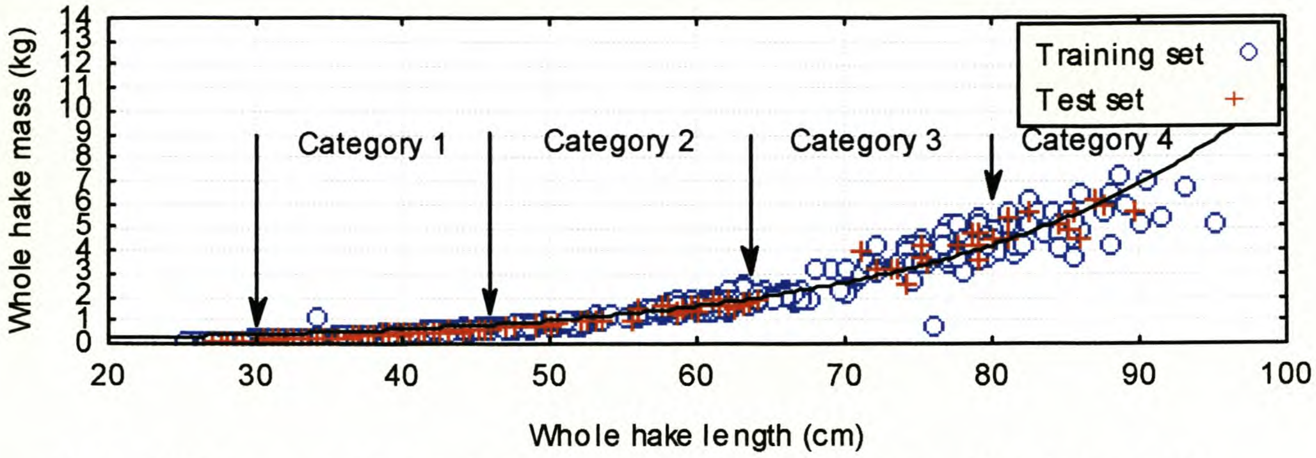


Figure 38. The pooled whole hake mass (kg) prediction models of boat trips 2 & 3.

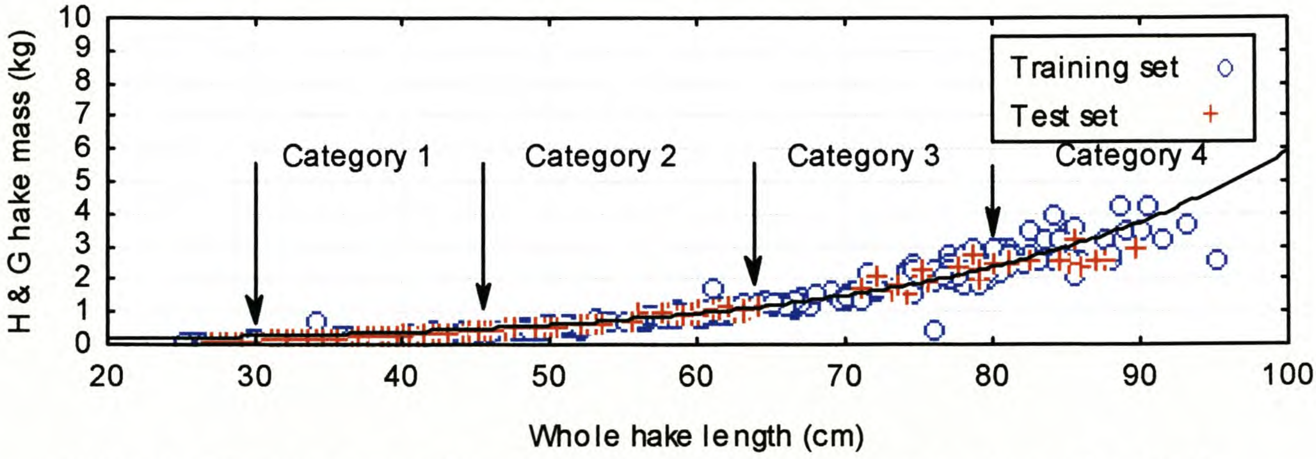


Figure 39. The pooled H & G hake mass (kg) prediction models of boat trips 2 & 3.

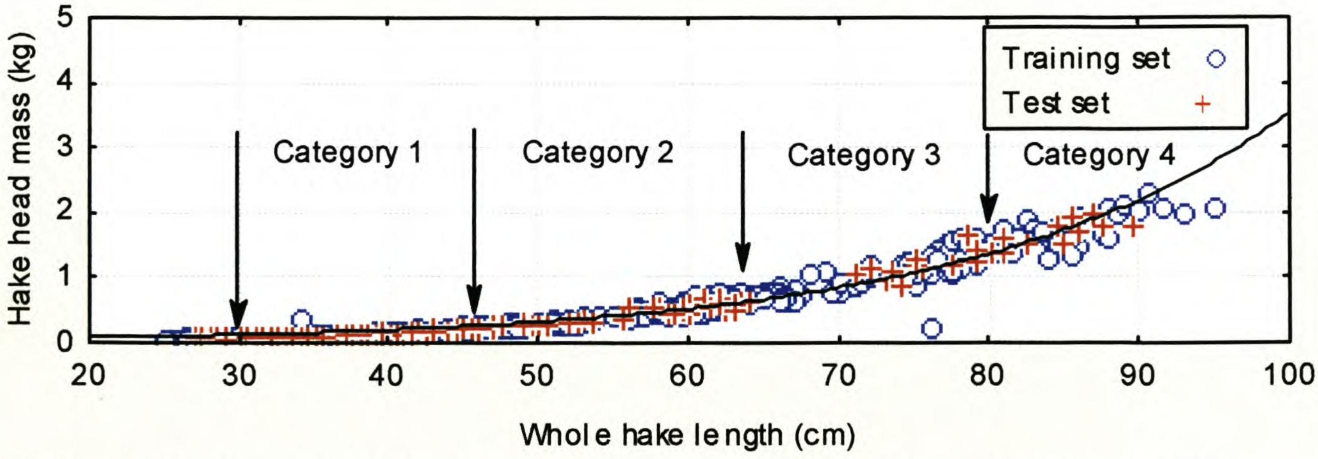


Figure 40. The pooled hake head mass (kg) prediction models of boat trips 2 & 3.

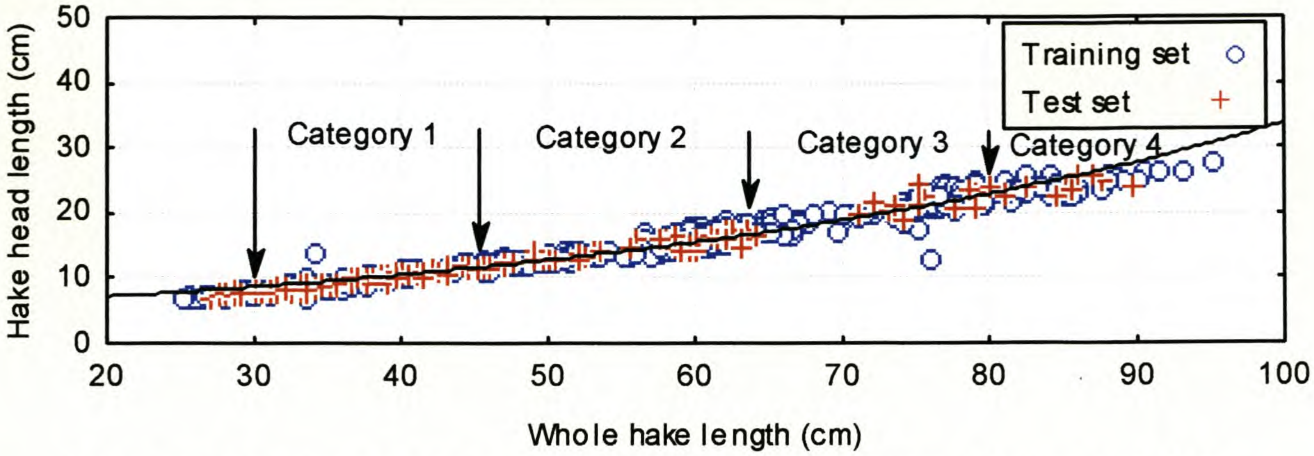


Figure 41. The pooled hake head length (cm) prediction models of boat trips 2 & 3.

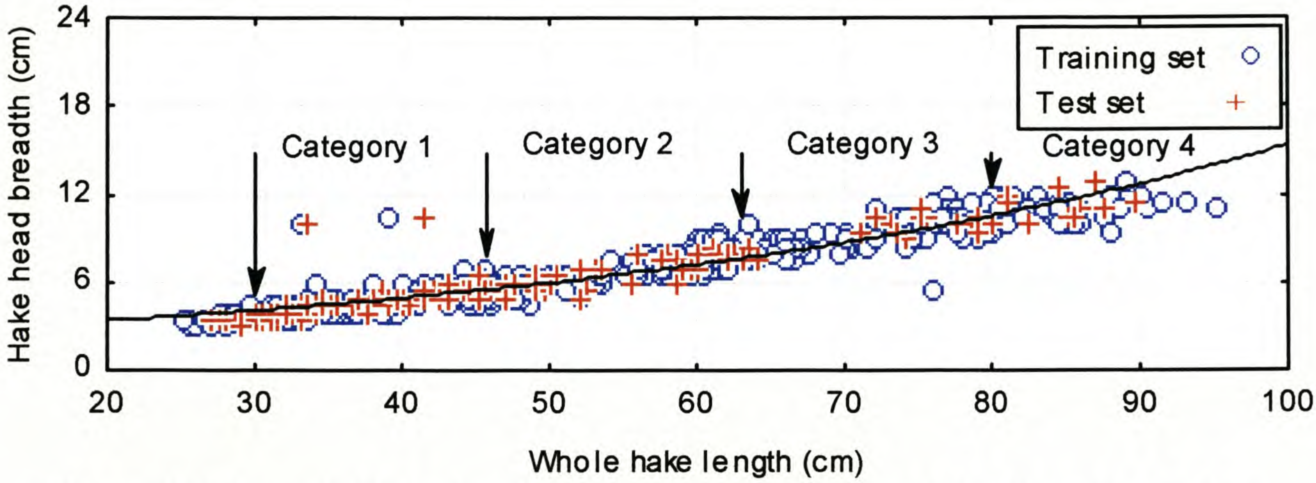


Figure 42. The pooled hake head breadth (cm) prediction models of boat trips 2 & 3.

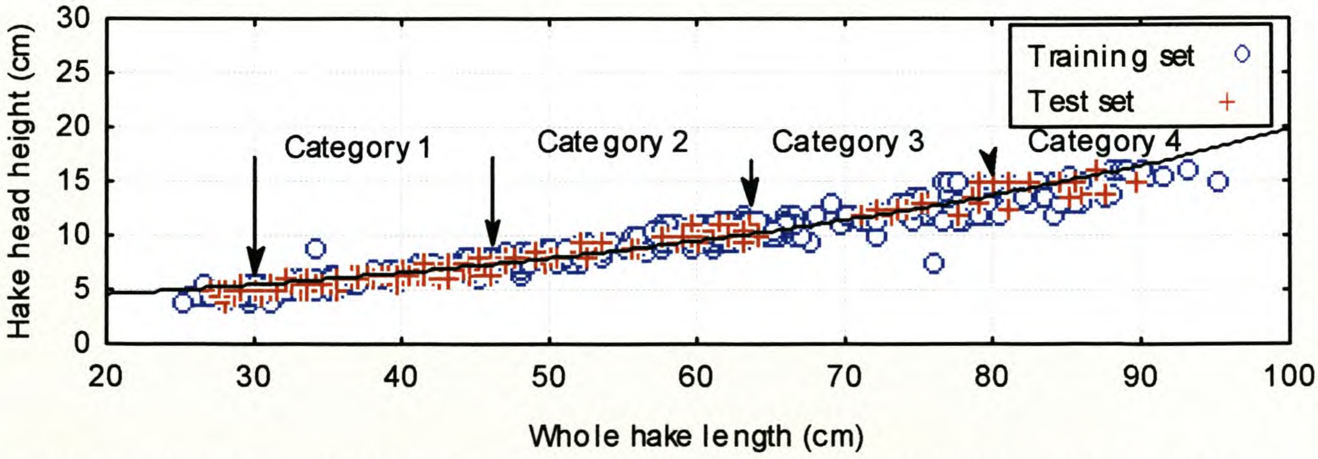


Figure 43. The pooled hake head height (cm) prediction models of boat trips 2 & 3.

Figures 44-49 show that there is a clear significant difference ($p<0.01$) between the respective prediction curves of boat trip 1 and respective pooled prediction curves of boat trips 2 and 3 which can be attributed to inadequate sample size (Punt *et al.*, 1992) of boat trip 1, with the exception of the hake head length (cm) prediction curve (Figure 47).

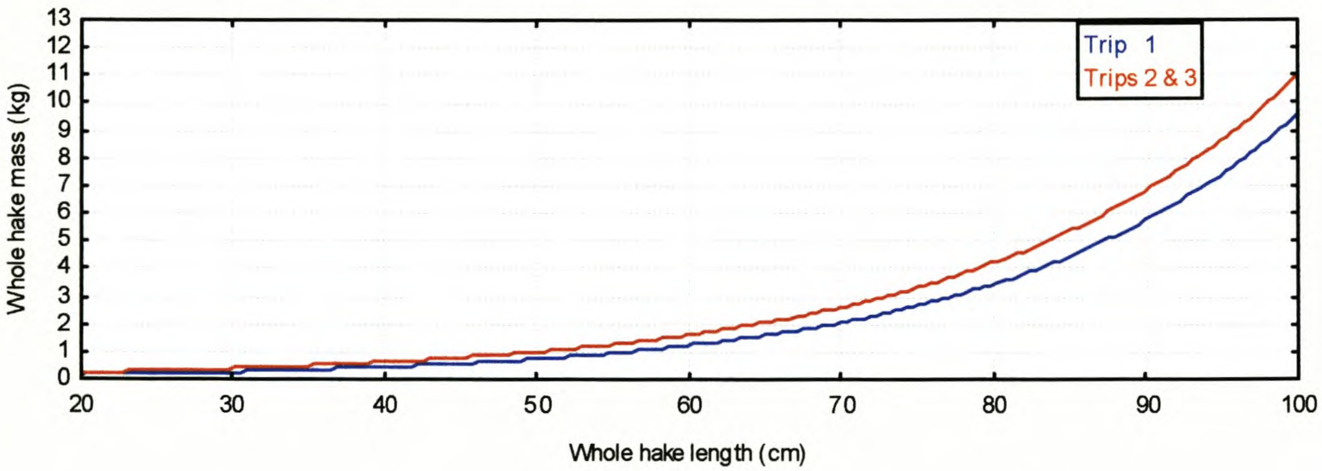


Figure 44. The whole hake mass (kg) prediction model of boat trip 1 & the pooled whole hake mass (kg) prediction models of boat trips 2 & 3.

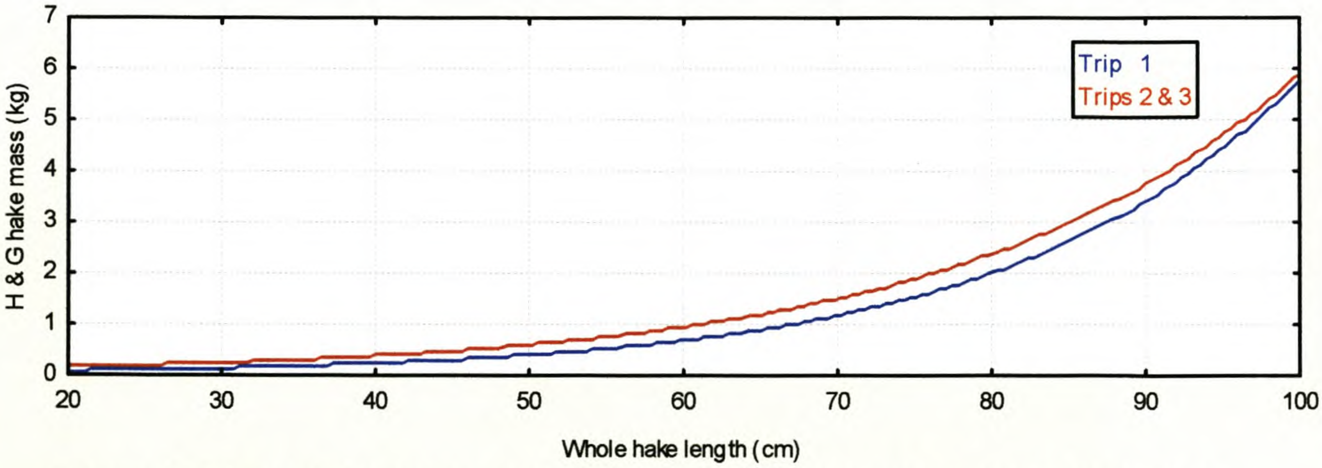


Figure 45. The H & G hake mass (kg) prediction model of boat trip 1 & the pooled H & G hake mass (kg) prediction models of boat trips 2 & 3.

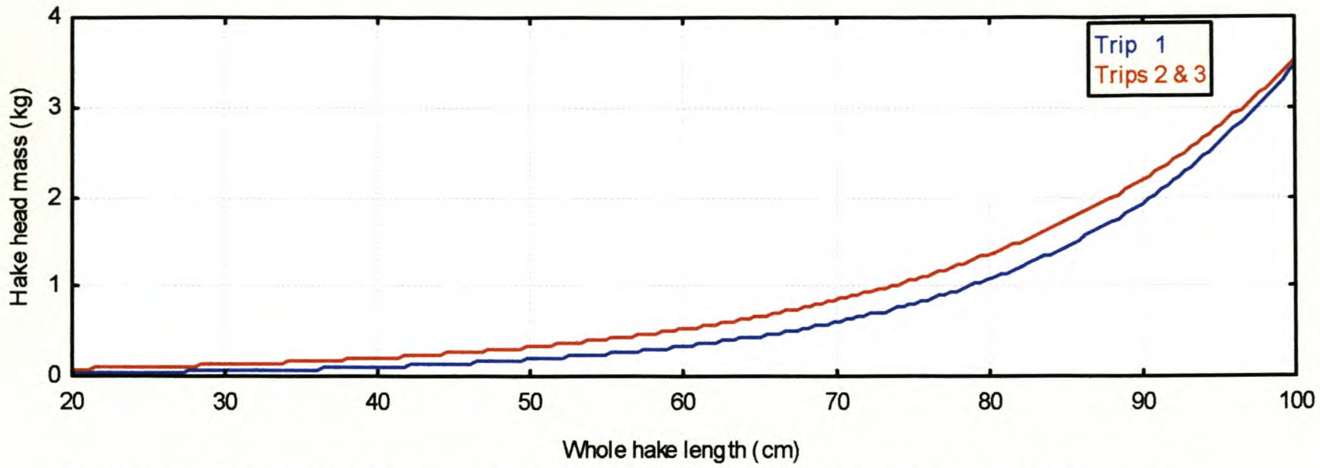


Figure 46. The hake head mass (kg) prediction model of boat trip 1 & the pooled hake head mass (kg) prediction models of boat trips 2 & 3.

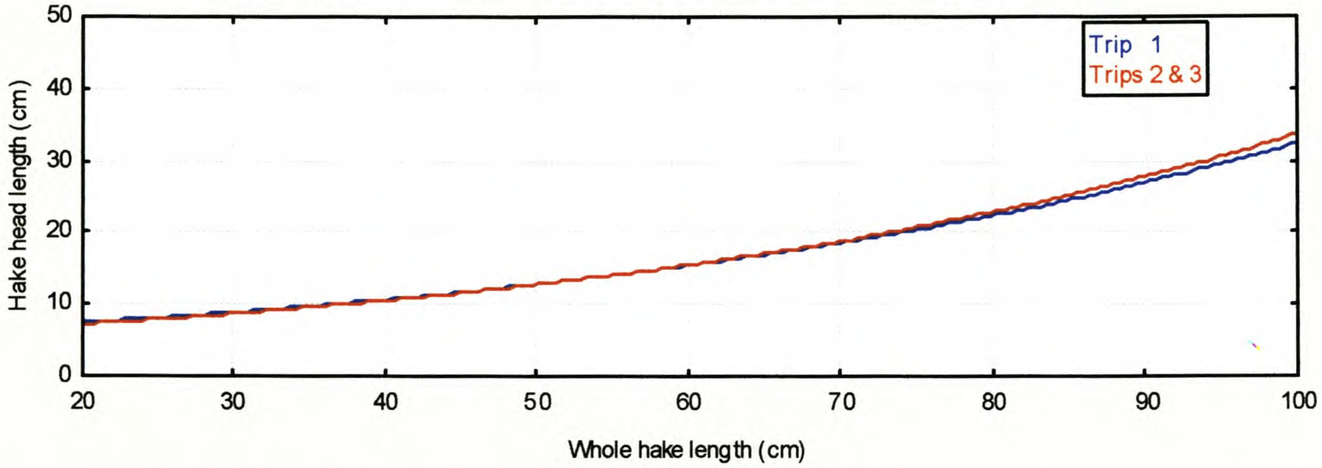


Figure 47. The hake head length (cm) prediction model of boat trip 1 & the pooled hake head length (cm) prediction models of boat trips 2 & 3.

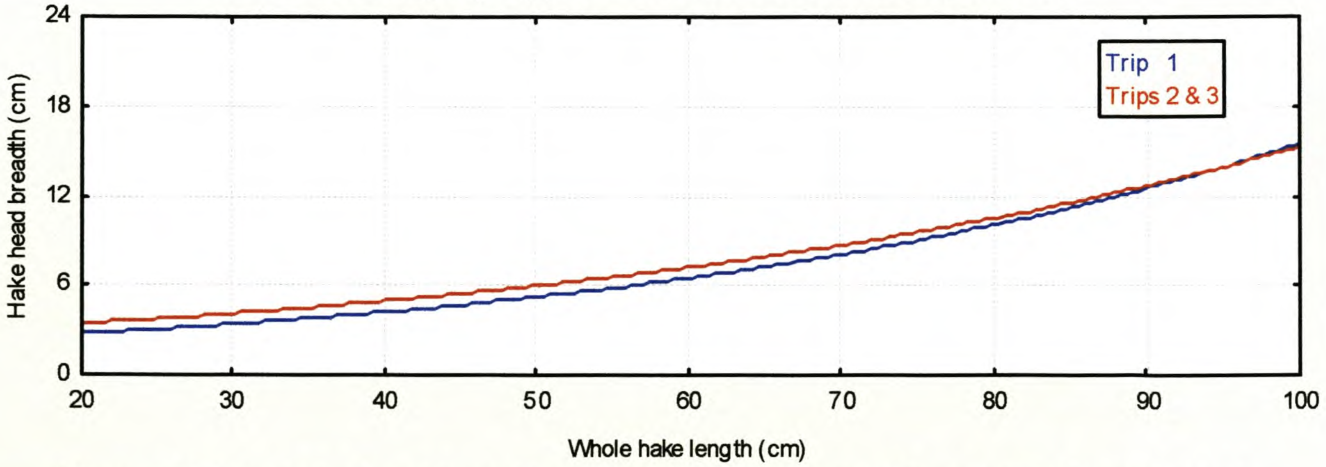


Figure 48. The hake head breadth (cm) prediction model of boat trip 1 & the pooled hake head breadth (cm) prediction models of boat trips 2 & 3.

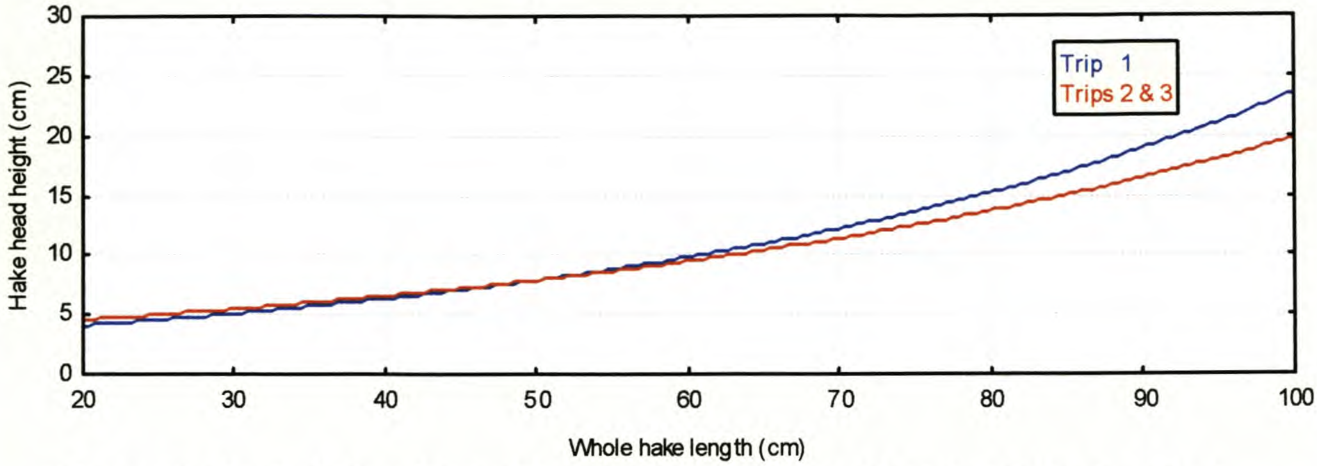


Figure 49. The hake head height (cm) prediction model of boat trip 1 & the pooled hake head height (cm) prediction models of boat trips 2 & 3.

The difference between the prediction models could not be attributed to diurnal vertical movement as all samples investigated were taken during daytime catches. The prediction models constructed for each of the three boat trips can be used in the fishing industry with relative confidence for Cape hake within the time frame each respective boat trip was carried out. Similarly, six prediction models were constructed for Cape hake trawled in and out of the main spawning season.

Conclusions

An increase in the variance of the data points of categories 3 and 4 for each of the six respective prediction models, per boat trip, was observed as opposed to categories 1 and 2. This could be attributed to firstly; a smaller sample size sampled for categories 3 and 4 and secondly that when investigating biological samples it is expected to find greater variance within the larger fish sizes. There was also a clustering of data in three areas for each prediction model namely; within category 1 and across categories 2 and 3, 3 and 4. This emphasizes the latitudinal stratification of the Cape hake population by age, hence the stratification by size. All the prediction models constructed for both boat trips 2 and 3 differed significantly from that in boat trip 1, with the exception of the hake head length (cm) prediction model. This may be attributed to the fact that boat trips 2 and 3 were sampled while the Cape hake were well into their main spawning season while those sampled during boat trip 1 was during the secondary spawning season. This difference between the prediction models of boat trips 2 and 3 and those constructed for boat trip 1 can, however, not be attributed to the diurnal feeding habit of Cape hake since all samples investigated were taken during daytime catches. Since data was pooled across geographical areas (increased representation) and an increasing sample size (increased precision) was sampled for boat trip 3 as opposed to boat trips 1 and 2 then the prediction models constructed from this boat trip, would be the most precise, should seasonal variation not be considered.

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Chapter 6

Chemical analysis and fatty acid composition of hake- (*Merluccius* ssp.) waste

Abstract

The samples for chemical proximate analysis were harvested onboard two wet-fish trawlers in Cape Town from the 25/08/01 to 26/08/01, 12/10/01 to 17/10/01 and 07/02/02 to 12/02/02, respectively. The first of the three turnarounds took place onboard wet-fish hake trawler A and the second and third on wet-fish hake trawler B, both forming part of the wet-fish hake trawler fleet of commercial fishing company B. The sampling procedure of hake heads was a random cumulative one for each of the four categories (i.e. predetermined divisions in centimeters into which each whole hake gets placed based on the total length of that hake – measurement taken from the tip of the snout to the tip of the caudal tail – categories 1 (30 - 46 cm), 2 (47 – 63 cm), 3 (64 – 80 cm) & 4 (>80 cm)) of hake head sections. During the final boat trip separate hake heads were sampled for both chemical analysis and fatty acid profile analysis in a single turnaround period. The chemical composition (i.e. moisture, protein, fat, ash, macro and trace mineral content) of the hake head sections (i.e. neck flesh, clean head, jaw, tongue, tongue cartilage, heart, gills, gut, kidney, intestine, gill cover, kidney & kidney bone and gut & gall) per category as well as the fatty acid profile of both the clean head and neck flesh of the study population (*Merluccius capensis* and *M. paradoxus*) off the Cape Town coastline was investigated during three separate boat trips. The hake head sections analysed, all had moisture contents above 70% with the highest being 85% (i.e. gut and kidney, category 2 and 3, respectively). The jaw having the lowest moisture content could be attributed to the presence of calcified bone, differing significantly ($p<0.05$) from all other hake head sections within categories for all boat trips. Significant differences ($p<0.05$) between sections within the same category could also be attributed to state of sexual maturation, seasonal differences or a combination of these factors. There seemed to be an inverse relationship between the moisture and ash content within each hake head section. The increase in the protein content across categories indicates a direct correlation between the protein content and the size of the hake head with the tongue having the highest protein content followed by the neck flesh

and clean head. The jaw also had a substantial amount of protein present given the fact that collagenous material is a major constituent of this section. Both the gut & gall and the intestines had a significantly ($p<0.05$) higher fat content than the rest of the hake head sections. The jaw conversely had the lowest fat content. The ash content differed significantly ($p<0.05$) within and across categories in the majority of the hake head sections. All significant differences ($p<0.05$) concerning the protein and fat content within a specific hake head section across categories could be attributed to state of sexual maturation, size of the fish, 'protein-water' line, different fish species, different sections of the fish under investigation and seasonal differences. Differences ($p<0.05$) in ash content across boat trips could be explained by the differences in sample sizes within categories across each boat trip. Another contributing factor may have been the fact that the second and third boat trips were carried out during the Cape hake main spawning season whereas the first boat trip was carried out during their secondary spawning season. All hake head sections (neck flesh, clean head, tongue cartilage, gills, gill covers and kidney & kidney bone) with a certain degree of bone present had considerable amounts of Ca present with the jaw having the highest Ca content. The neck flesh, jaw, gills, kidney & kidney bone and gut & gall, however, contained considerable amounts of Fe followed by Zn in comparison to the other trace elements. Both the jaw and the tongue cartilage are good sources of P, K, Ca and Na with the tongue cartilage also having the highest amount of Cu, Zn and Pb. As expected docosahexaenoic (DHA) was the main n-3 fatty acid present in both the clean head and neck flesh, per category. In the clean head section the most prominent n-6 fatty acid present was arachidonic acid whereas linolenic acid was most prominent in the neck flesh. For both the clean head and neck flesh there seemed to be an inverse relationship between SFA and MUFA as well as between n-3 and n-6 fatty acids.

Introduction

Non-marketable fish-waste is normally disposed of as discards since time, money and effort are spent on onboard preservation thereof, resulting in a waste of a potential protein source (Clucas, 1996). This predicament can, however, shift from one concerned about onboard fish preservation to one investigating the potential chemical composition of this wasted protein source, resulting in, informed decisions of future matters concerning the disposal thereof. Scudder (1992) deemed it important that research into the chemical composition and properties of bycatch and their suitability for different types of processing take place before commercial development can begin. It is thus of utmost importance that a pilot study be executed and sufficient knowledge be obtained about the study population before full-scale research takes place. This is in agreement with Punt *et al.* (1992) who deemed simulation studies advisable in order to assess the sampling intensity required to achieve the desired levels of accuracy (low bias) and precision (low variance) for predictions.

The study population under investigation is the Cape hake (*Merluccius capensis* and *M. paradoxus*) and both morphological and chemical status data concerning hake-waste is important before large-scale commercial development can begin. Both species of Cape hake spawn throughout the year (Jones & Van Eck, 1967), however, the main spawning season usually occurs during spring extending from September to December/January (Botha, 1974; O'Toole, 1978; Hamukuaya, 1994). Botha (1986) describes Cape hake spawning as a double wave, firstly in November/December by both species concerned and secondly in February/March which is mainly dominated by the *M. paradoxus* species. Roel & MacPherson (1988) also found that feeding intensity decreases during the spawning season (less pronounced diurnal vertical feeding migration-concentrates on ocean floor during the day and feeds in midwaters at night). Cape hake are opportunistic feeders, which will exploit suitable prey when encountered rather than feeding at specific times of the day or night (Pillar & Barange, 1997). Increased variance can be attributed to a small sample size (Punt *et al.*, 1992). Even though predictions may be deemed imprecise due to the effects of a small sample size, pooled data is nevertheless regarded as more precise (Punt *et al.*, 1992). It is also important to remember that calculated conversion factors for a given species are subjected to variation between different areas due to variations in biological factors (i.e. availability of food and maturity state of fish) and cleaning processes (Chalmers, 1976).

The condition of *M. capensis* decreases as the fish length increases which may be attributed to the smaller fish having a higher metabolic rate as opposed to the bigger fish (Preński, 1980). These smaller fish have a lower fat accumulation than the larger fish, which could be attributed to their intensive growth rate with the lower fat values for the medium-size fish explained by their switch in diet from *Gobiidae* and *Euphausiacea* to *Merluccius* ssp. as their main food item (Preński, 1980).

Photomicrographs of anchovy muscle showed a steady increase in the proportion of dark muscle from head to tail; tail muscle having over six times the proportion of dark muscle as compared with that near the head (Johnston, 1982). The total ash content of different organs did not appear to vary greatly as reported by Braekkan (1958) who found that the percentage ash present in the male and female gonads (1.4%); stomach (1.2%); pyloric caecae, muscle, spleen and kidney (1.1%); heart (1.0%) and gills (0.9%) of *Gadus morhua* (cod), which forms part of the gadoid species (Love, 1988), were quite similar.

Myofibrils are highly organised muscle structures similar to whole muscle, which are useful for the study of the contractile proteins of skeletal muscle (Yasui *et al.*, 1975). Beas *et al.* (1991) studied the thermal denaturation of myofibrillar proteins from pre- and post-spawned hake and the data obtained showed that the myosin denaturation rates were greater for post-spawning than for pre-spawning hake, indicating that proteins of fish in a better biological condition (post-spawned) denature more rapidly and completely than does pre-spawned hake. Beas *et al.* (1991) and attributed this to the fact that 1) Ca^{2+} sensitivity of myofibrils from pre-spawned hake was 40% less than that of myofibrils from post-spawned hake; 2) that myofibrils from post-spawned hake have more active biochemical and functional properties than those from pre-spawned hake and finally 3) that the enzymatic activities at zero time from post-spawned hake were three times higher than those from pre-spawned hake. Therefore, from the aforementioned conclusions it is deduced that the biological condition related to the reproductive cycle influences biochemical and functional properties.

The slower production of new fibres in fish with body lengths greater than about 40 cm may have resulted from the onset of maturity, which causes a drain on the protein resources of the fish (Greer-Walker, 1970). This is more commonly known as the 'protein-water line' in non-fatty fish where the protein and moisture content are inversely proportional to each other (Brandes & Dietrich, 1958). Ross & Love (1979) showed that cod muscle at the start of their spawning season, was accompanied by a breakdown of proteins. Observations by Eliassen & Vahl (1982) showed that the protein depletion of cod muscle as measured by the rise in water content is the same in mature, spawning cod as in immature cod of the same size; that is, the extra energy taken from the diet by mature fish is enough to compensate for the extra drain of greater gonad growth. However, when bigger cod from the North Sea are considered, it is clear that their muscle is more depleted of proteins as their body lengths increase (Eliassen & Vahl, 1982). The 'protein-water line' pointed out shows that a decrease in one constituent is matched by an increase in the other, but the changes are not completely equivalent.

Martínez-Valverde *et al.* (2000) concluded, after investigating four commercial fish species including *Merluccius merluccius* L., where quantities of Fe, Cu and Zn were quite low while the Ca and P quantities were higher when bone was present. The bone was therefore shown to be a good source of Ca and P. Fish flesh is also an important source of minerals since it can contain up to 1 mg.100 g^{-1} of K, Na, Cl, Mg, P, Ca as well as Fe, Zn, Cu, and I, though in lower quantities (Paul & Southgate, 1978; Navarro, 1991).

The results of analytical, nutritional or technological experiments on musculature are likely to vary according to the portion sampled. Similarly, one can conclude that the chemical status of different associated hake-waste sections across both category and boat trips can either vary or be quite similar due to their state of sexual maturation, seasonal change or size of the fish.

Chemical structures of fatty acids share some common characteristics (Coetzee, 2000). Fatty acids are designated by the number of carbon atoms followed by a colon and the number of unsaturated bonds with the first double bond identified from the methyl end with an omega (ω or n-) character (Tichelaar, 1998). Fatty acids consist of a straight carbon chain with a terminal carboxyl group with the vast majority of natural occurring fatty acids having an even number of carbon atoms present (Coetzee, 2000). Fatty acids with twelve or more carbon atoms are referred to as long-chain fatty acids (mutton and beef fat). Conversely, short-to-medium-chain fatty acids (4-6 or 8-12 carbon atoms) result in a lowering of the melting point, which accounts for the relative softness of butterfat and oils. The degree of saturation of fatty acids refers to the presence or absence of double bonds. When a fatty acid is saturated, it means that the carbon atoms bond with all of the hydrogen atoms they can and are thus saturated with hydrogen. A fatty acid that contains double bonds is said to be unsaturated and contributes to the low melting points typical of oils. Oleic acid contains one double bond and is therefore termed monounsaturated. A fatty acid with more than one double bond is said to be polyunsaturated (Coetzee, 2000).

There are two classes of polyunsaturated fatty acids (PUFA's); n-6 and n-3 fatty acids also known as essential fatty acids (EFA) because humans cannot synthesise them and must obtain them from their diet (Tichelaar *et al.*, 1994; Tichelaar, 1998). Linoleic acid (LA) and α-Linolenic acid (ALA) respectively represent the n-6 and n-3 series (Tichelaar, 1998). An imbalance between n-6 and n-3 fatty acids can be related to various diseases, because both types of fatty acids compete for the same enzyme systems (Tichelaar, 1993). However, both are necessary for the normal functioning of the body's metabolic, growth and renewal processes (Tichelaar, 1993). α-Linolenic (n-3 fatty acids) acids are essential fatty acids in man, which are obtained through an elongation and desaturation process to eicosapentanoic acid (EPA; C20:5n-3), although the capacity to do so is limited (Bjerve *et al.*, 1988). EPA has been reported to exert beneficial effects in arteriosclerosis, coronary heart disease and rheumatoid arthritis (Bjerve *et al.*, 1988).

Fish oils are generally rich in n-3 fatty acids with a high content of eicosapentanoic (EPA) and docosahexanoic acid (DHA; C22:6n-3) and are commercially available in gelatin encapsulated forms. DHA is the most important fatty acid and also the most unsaturated (Love, 1988; Méndez *et al.*, 1996). Méndez *et al.* (1996) reported that both EPA and DHA are the main polyunsaturated fatty acids in several fish species whereas palmitic and oleic acid are the main saturated and monounsaturated fatty acids, respectively. Changes in DHA fatty acids in particular are important to processors, since oxidation of this substance is largely responsible for the development of off-flavour and off-odour during cold-storage (Love, 1970, 1988). Several studies have established that the concentrations of fatty acids are influenced by the type of fish, their size and lipid content with that of hake having the highest levels of n-3 fatty acids (Candela *et al.*, 1997).

The objectives of this study were therefore to:

- Chemically analyse (moisture, protein, fat, ash, macro and trace mineral content) the chemical composition of the hake head sections (neck flesh, clean head, jaw, gills, tongue, tongue cartilage, heart, gut, kidney and intestines); and
- Determine the chemical composition (moisture, protein, fat, ash, macro and trace mineral content) and fatty acid profile of the neck flesh and clean head sections over a single turnaround period.

Materials and methods

Harvesting procedure

The samples for chemical proximate analysis were harvested onboard three wet-fish trawlers in Cape Town from 25/08/01 to 26/08/01, 12/10/01 to 17/10/01 and 07/02/02 to 12/02/02, respectively. The first of the three turnarounds took place onboard wet-fish hake trawler A and the second and third on wet-fish hake trawler B. These are the same wet-fish hake trawlers as in Chapter 5 and thus the hake heads used in this study were the same that were used to develop the prediction models in Chapter 5. The sampling procedure of hake heads was a random cumulative one for each of the four categories of hake head sections. During the final boat trip separate hake heads were sampled for both chemical analysis and fatty acid profile analysis in a single turnaround period. Only the neck flesh and clean head sections were analysed for both their fatty acid profile per category over a six day period as well as their chemical composition, whereas all ten hake head sections were analysed for their chemical composition status, hence the fact that the remaining eight hake head sections (jaw, gills, tongue, tongue cartilage, heart, gut, kidney and intestines) from the hake heads sampled for fatty acid profile analysis were included in the respective eight hake head sections for each of the four categories in the hake heads sampled for chemical proximate analysis. Therefore, the neck flesh and clean head sections that were chemically analysed in the third and final boat trip were fewer than that of the remaining eight hake head sections. The clean head and neck flesh destined for fatty acid profile analysis were, however, also investigated for its chemical status (i.e. moisture, protein, fat and ash content).

Samples and sample preparation

The sectioning and mincing procedures for the first and second boat trips were executed at a processing company and the chemical analyses were carried out at the Departments of Food (moisture and ash) and Animal Sciences (protein and fat), Stellenbosch University. The hake heads sampled on the third boat trip were minced at the Department of Animal Sciences, Stellenbosch University. The only sample preparation difference between the first, second and third boat trip samples was that chemical analysis was performed on the wet minced hake head sections per category of the first and second boat trips whereas the protein and fat samples sampled during the third boat trip was first freeze dried (due to inconsistent homogeneity) before chemical analysis was carried out. Freeze drying involved weighing off appropriate amounts of wet minced sample into plastic containers and freeze drying it for 24 hours in a Centrifugal Freeze Dryer (Model: 30P.2/782), after which it was then milled through a 20-mesh sieve before duplicate analysis took place. The wet minced samples, however, were deemed homogenous enough for ash and moisture determination.

Hake head sections analysed for mineral analysis was performed, at Elsenberg (Department of Agriculture, Western Cape), on the ten hake head sections of the first and second boat trips as well as the clean head and neck flesh sections sampled during the third boat trip.

The sectioning and mincing of samples for fatty acid profile analysis took place at a processing company considering only the neck flesh and clean head sections per category. The remaining eight hake head sections were included into its respective category per hake head section for those samples, sampled during the third boat trip, destined for chemical analysis of the ten hake head sections. For each of the four categories of the first boat trip 22, 72, 17 and 4 hake heads were sampled for categories 1, 2, 3 and 4, respectively. During the second boat trip 45, 53, 45 and 40 hake heads were sampled for categories 1, 2, 3 and 4, respectively. However, hake heads sampled during the third and final boat trip involved sampling for chemical analysis (ten hake head sections), fatty acid profile and composition analysis (neck flesh and clean head sections) samples. During this boat trip 126, 100, 42 and 48 hake heads were sampled for both fatty acid profile and chemical composition analysis whereas 74, 53, 43 and 20 hake heads were sampled for chemical proximate analysis of the ten hake head samples for categories 1, 2, 3 and 4, respectively. Due to reasons mentioned earlier the number of hake head sections analysed for chemical composition sampled from the third boat trip were 74, 53, 43 and 20 (neck flesh and clean head sections) and 200, 153, 85 and 68 (jaw, tongue, tongue cartilage, heart, gut, kidney and intestines sections) for categories 1, 2, 3 and 4, respectively. The hake heads were first sectioned and then each section divided into four batches, where possible, followed by mincing of each of the four batches per hake head section. These minced samples were vacuum packed and frozen. The frozen samples were thawed at 0°C before duplicate analyses were performed on each of the four minced batches of each hake head section.

Analytical assays

Moisture determination

The moisture determination was performed as described by James (1996). Metal dishes containing *ca.* 20 g of acid washed sand and a glass rod were dried in a vacuum oven (68 - 72°C) for 30 minutes before weighing off 5 ± 0.01 g of sample. The glass rod was used to aid the mixing of the sample with the acid washed sand after which it was placed on a water bath for *ca.* 30 minutes until all excess water had been evaporated from the sample. The metal dishes containing the acid washed sand, glass rod and sample were placed in an air-drying oven (101 - 105°C) for 15 - 18 hours. The difference in mass between the wet and dried sample was calculated, which was then converted into a percentage.

Protein determination

The percentage protein present was determined according to the official AOAC Method 2001.11 (AOAC, 2002). Only *ca.* 0.5 ± 0.001 g of freeze dried sample, as compared to the *ca.* 2 ± 0.01 g needed for wet sample, was weighed for each hake head section per category sampled during the third boat trip.

Fat determination

Determination of the percentage fat present in the samples was performed as described by Lee *et al.* (1996). The freeze dried hake head sections per category sampled during the third boat trip had to be rehydrated with distilled water (*ca.* 1 ± 0.01 g + 4 ml dH_20) before chemical analysis could be executed. Once again a much smaller freeze dried sample mass was needed as compared to the analysis of a wet sample (*ca.* 5 ± 0.01 g).

Ash determination

The ash determination was performed as described by James (1996). The crucibles were dried in a muffle furnace at a temperature of 550°C for 30 minutes before weighing off 5 ± 0.01 g of sample into each crucible. Five ml of magnesium acetate alcohol was, however, added to the sample (to aid the burning process), before gentle heating over a Bunsen burner until the sample was charred. The crucibles containing the charred sample was then transferred to a muffle furnace at 550°C for 15 - 18 hours until a white or light grey ash was formed. The difference in mass between the wet and charred sample was calculated, which was then converted into a percentage.

Mineral determination

The determination of the percentage macro and trace elements present in the ten hake head sections per category was performed by Elsenberg. Only single analysis was carried out and sample preparation involved "dry ashing" as described by Giron (1973) and total nitrogen was determined according to the AOAC Method 955.04 (AOAC, 1995). The macro and trace elements were determined using an Axial Simultaneous ICP (Thermo Jarrell Ash Iris (TJA Iris) HiRes).

Fatty acid determination

The fatty acid extraction was performed according to Folch *et al.* (1957), while the methylation process was performed according to the method described by Butte (1983). The gas chromatograph used was a Hewlett Packard 5890 series II, equipped with a flame ionisation detector and a Supelcowax 10 fused glass capillary column (30 m X 0.53 mm id.) with nitrogen as a carrier gas at a flow rate of 2 ml.min^{-1}. The oven temperature increased from 120°C (held for 3 min.) at a rate of $3^{\circ}\text{C.min}^{-1}$ to 225°C (held for 10 min.) and then to 245°C again at a rate of $3^{\circ}\text{C.min}^{-1}$, where it was maintained until all peaks were eluted. A 1 µl sample was injected at a split ratio of 1:50 with an inlet temperature of 230°C.

Statistical analysis

ANOVA was used to determine significant differences in chemical content between the different sections within a category as well as across boat trips. The graphs were compiled using Statistica version 6. Every point on the graph indicates the average value calculated from two duplicates in four batches (eight values). The bar indicated at each value represents the 95% confidence interval for the average. A 5% significance level ($p<0.05$) was used as guideline for determining significant differences. For post-hoc tests, Bonferroni was used.

Results and discussion

Chemical composition

Moisture

Table 1 shows the statistical differences between average moisture content for the respective hake head sections within boat trips for each category as well as across categories (Detailed results in Appendix 4, Table 1). The hake head sections analysed all had moisture contents above 70% with the highest approximate moisture content being 85% (eg. gut and kidney, category 2 and 3, respectively) which is in agreement with prior work reported in Chapter 4. Braekkan (1958) reported that the moisture content of various sections of cod (*Gadus morhua*) differ between 74 and 85%. The moisture content of the jaw was the lowest and differed significantly ($p<0.05$) from all the other hake head sections within categories for all boat trips. It was expected for the jaw to have the lowest moisture content due to the large portion of calcified bone present.

Table 1 shows that there was a decrease in moisture content, although, not always significant, within each respective hake head section across categories. It is therefore assumed that the larger the size of the hake the more calcified bone material is present, and that these samples will have a higher ash and lower moisture content indicating an inverse relationship between the moisture and ash contents. There were only significant differences ($p<0.05$) within a respective hake head section across categories in both the neck flesh and gills between categories 2 and 4; and the tongue between categories 3 and 4. The significant differences ($p<0.05$) between sections within the same category could be attributed to the difference in the degree of presence or absence of bony material. Other contributing factors could be the state of sexual maturation, seasonal differences or a combination of these factors. The moisture content of the neck flesh, clean head and jaw differed significantly ($p<0.05$) across boat trips within each category (Table 2). This was expected since the jaw and clean head is made up mainly of bony collagenous material whereas the neck flesh consists mainly of hake muscle. Similarly, the gills differed significantly ($p<0.05$) between boat trips 2 and 3 within categories 2 and 4, respectively.

Table 1. Statistical differences between average moisture content for the respective hake head sections within boat trips for each category as well as across categories.

		Moisture content (%)			
		Category			
Boat trip	Hake head section	1	2	3	4
1	Neck flesh	*	82.87 bc ± 0.27	*	*
1	Clean head	*	84.22 c ± 0.66	*	*
1	Jaw	*	77.82 a ± 0.55	*	*
1	Gills	*	84.17 c ± 0.33	*	*
1	Gut & gall	*	82.16 bc ± 0.53	*	*
1	Kidney & kidney bone	*	80.87 b ± 0.86	*	*
2	Neck flesh	*	83.91 def ± 0.24	83.00 cdef ± 0.17	79.28 abc ± 0.44
2	Clean head	*	82.87 cdef ± 0.80	82.81 bcdef ± 0.54	79.49 abc ± 1.58
2	Jaw	*	79.64 abcd ± 0.63	76.44 a ± 0.82	*
2	Gills	*	84.78 def ± 0.09	81.09 bcde ± 0.55	79.68 abc ± 1.34
2	Tongue	*	*	82.87 bcdef ± 0.75	79.05 ab ± 0.32
2	Tongue cartilage	*	*	82.62 bcdef ± 0.08	76.08 a ± 0.62
2	Gut	*	*	85.76 f ± 0.35	85.09 f ± 0.11
2	Kidney	*	*	*	84.65 ef ± 0.11
3	Neck flesh	83.46 lm ± 0.54	78.93 ghijk ± 1.00	75.32 defg ± 0.47	74.18 cdef ± 0.56
3	Clean head	81.47 hijklm ± 0.92	79.29 ghijkl ± 1.19	78.37 fghi ± 0.97	70.76 bc ± 1.56
3	Gills	83.77 m ± 0.30	81.57 ijklm ± 0.75	78.68 ghij ± 0.83	73.85 cde ± 0.84
3	Gut	85.16 m ± 1.06	84.98 m ± 0.58	84.24 m ± 1.19	83.01 jklm ± 0.44
3	Jaw	77.08 efgh ± 0.52	71.42 bcd ± 0.58	69.36 ab ± 1.01	65.70 a ± 1.20
3	Tongue	*	83.71 klm ± 0.31	80.85 hijklm ± 0.30	79.13 ghijkl ± 0.51
3	Tongue cartilage	*	80.99 hijklm ± 0.08	81.47 hijklm ± 0.93	75.83 defg ± 0.83
3	Kidney	*	85.57 m ± 0.23	84.41 m ± 0.53	84.21 m ± 0.62
3	Intestines	*	83.08 ijklm ± 0.53	83.33 klm ± 0.35	83.56 lm ± 0.24
3	Heart	*	*	*	83.88 jklm ± 0.13

Means with different letters within each boat trip differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Table 2. Statistical differences between average moisture content for the respective hake head sections across boat trips within each category.

Moisture content (%)				
			Boat trip	
Category	**Hake head section**	**1**	**2**	**3**
2	Neck flesh	82.87 bc ± 0.27	83.91 ab ± 0.24	78.93 def ± 1.00
2	Clean head	84.22 efg ± 0.66	82.87 def ± 0.80	79.29 gh ± 1.19
2	Jaw	77.82 j ± 0.55	79.64 i ± 0.63	71.42 k ± 0.58
2	Gills	84.17 de ± 0.33	84.78 cd ± 0.09	81. 57 fgh ± 0.75
2	Gut & gall	82.16 ab ± 0.53	*	*
2	Kidney & kidney bone	80.87 gh ± 0.86	*	*
2	Tongue	*	*	83.71 a ± 0.31
2	Tongue cartilage	*	*	80.99 hi ± 0.08
2	Kidney	*	*	85.57 abc ± 0.23
2	Gut	*	*	84.98 a ± 0.58
2	Intestines	*	*	83.08 abc ± 0.53
3	Neck flesh	*	83.00 de ± 0.17	75.32 b ± 0.47
3	Clean head	*	82.81 de ± 0.54	78.37 bc ± 0.96
3	Jaw	*	76.44 b ± 0.82	69.36 a ± 1.01
3	Tongue	*	82.87 cde ± 0.75	80.85 cd ± 0.30
3	Tongue cartilage	*	82.62 cde ± 0.08	81.47 cd ± 0.93
3	Gills	*	81.09 cd ± 0.55	78.68 bc ± 0.83
3	Gut	*	85.76 e ± 0.35	84.24 de ± 1.19
3	Intestines	*	*	83.33 de ± 0.35
3	Kidney	*	*	84.41 de ± 0.53
4	Neck flesh	*	79.28 de ± 0.44	74.18 bc ± 0.56
4	Clean head	*	79.49 de ± 1.58	70.76 b ± 1.56
4	Tongue	*	79.05 de ± 0.32	79.13 de ± 0.51
4	Tongue cartilage	*	76.08 cd ± 0.62	75.83 cd ± 0.83
4	Gills	*	79.68 def ± 1.34	73.85 bc ± 0.84
4	Gut	*	85.09 g ± 0.11	83.01 efg ± 0.44
4	Kidney	*	84.65 g ± 0.11	84.21 fg ± 0.62
4	Intestines	*	*	83.45 efg ± 0.03
4	Heart	*	*	83.88 efg ± 0.13
4	Jaw	*	*	65.70 a ± 1.20

Means with different letters within each category differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Proteins

Table 3 shows an increase in the protein content, although not always significant, of the respective hake head sections across categories (Detailed results in Appendix 4, Table 1). Within results of boat trip 3 there was a higher degree of significance due to more representative samples within each category. The increase in the protein content across categories indicates a direct correlation between the protein content and the size of the hake head. Significant differences ($p<0.05$) within a specific hake head section across categories could be attributed to one of several factors namely, state of sexual maturation (Eliassen & Vahl, 1982; Ross & Love, 1979), size of the fish (Greer-Walker, 1970) or to the inverse relationship between the protein and moisture content (Table 1), which is known as the 'protein-water' line (Brandes Ditriech, 1958; Love, 1970; Eliassen & Vahl, 1982).

The sections with the highest protein contents were the tongue, followed by the neck flesh and clean head. Although the neck flesh and tongue did not differ significantly ($p<0.05$) within categories (except within category 4, boat trip 2) the neck flesh would be regarded as the ideal section for a potential protein source due to available quantity which confirms earlier results (14.96%, Chapter 4). The intestines (10.50%) had the lowest protein content (Table 3).

The jaw, which is high in cartilaginous material had a substantial amount of protein present. There was no significant difference ($p>0.05$) in the protein content in the respective hake head sections across boat trips 2 and 3 (Table 4). However, significant differences did occur between boat trips 1 and 2 (neck flesh and clean head) and boat trips 1 and 3 (jaw) (Table 4). This increasing protein content in the jaw section is contradictory to previous findings (Ross & Love, 1979; Eliassen & Vahl, 1982) who attributed a drain on protein resources of the fish muscle to spawning. One can therefore deduce that the results of chemical analyses on muscle are therefore likely to vary according the section analysed, which confirms findings by Tsukamoto (1984).

Table 3. Statistical differences between average protein content for the respective hake head sections within boat trips for each category as well as across categories.

		Protein content (%)			
		Category			
Boat trip	Hake head section	1	2	3	4
1	Neck flesh	*	15.50 d ± 0.26	*	*
1	Clean head	*	13.26 c ± 0.30	*	*
1	Jaw	*	12.80 bc ± 0.05	*	*
1	Gills	*	11.88 ab ± 0.26	*	*
1	Gut & gall	*	11.78 a ± 0.13	*	*
1	Kidney & kidney bone	*	12.96 c ± 0.17	*	*
2	Neck flesh	*	18.79 def ± 0.27	19.05 def ± 0.73	18.49 cde ± 0.36
2	Clean head	*	16.12 abcd ± 0.89	16.96 bcde ± 0.59	16.30 abcd ± 0.88
2	Jaw	*	15.53 abcd ± 0.19	18.73 def ± 0.34	*
2	Gills	*	12.76 a ± 0.62	16.52 bcde ± 0.99	16.48 bcd ± 0.41
2	Tongue	*	*	20.18 ef ± 0.31	21.70 f ± 0.40
2	Tongue cartilage	*	*	14.86 abc ± 0.71	17.19 bcde ± 0.40
2	Gut	*	*	14.43 ab ± 0.12	15.03 ab ± 0.36
2	Kidney	*	*	*	14.48 ab ± 0.13
3	Neck flesh	13.11 abcdefg ± 0.45	16.65 hijkl ± 0.77	19.58 cdef ± 0.39	21.17 n ± 0.57
3	Clean head	13.56 abcdefgh ± 0.78	14.60 cdefghi ± 0.92	15.31 efghi ± 0.68	21.49 n ± 0.94
3	Gills	10.94 ab ± 0.10	12.68 abcde ± 0.49	15.49 efghi ± 0.63	19.38 klmn ± 0.69
3	Gut	11.71 abcde ± 0.79	12.32 abcde ± 0.52	13.94 bcdefghi ± 1.09	14.84 defghi ± 0.37
3	Jaw	12.40 abcde ± 0.27	16.04 fghij ± 0.29	17.21 ijklm ± 0.60	20.04 mn ± 0.36
3	Tongue	*	16.42 ghijkl ± 0.34	19.06 jklmn ± 0.44	20.67 n ± 0.49
3	Tongue cartilage	*	12.06 abcde ± 0.09	12.79 abcdef ± 0.86	16.28 ghijk ± 0.58
3	Kidney	*	11.16 abc ± 0.21	11.74 abcd ± 0.31	11.79 abcd ± 0.48
3	Intestines	*	11.63 abcd ± 0.36	10.91 ab ± 0.18	10.50 a ± 0.25
3	Heart	*	*	*	13.51 abcdefghi ± 0.07

Means with different letters within each boat trip differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Table 4. Statistical differences between average protein content for the respective hake head sections across boat trips within each category.

		Protein content (%)		
			Boat trip	
Category	**Hake head section**	**1**	**2**	**3**
2	Neck flesh	15.50 ce ± 0.26	18.79 f ± 0.27	16.65 ef ± 0.77
2	Clean head	13.26 abcd ± 0.30	16.12 e ± 0.89	14.60 bcde ± 0.92
2	Jaw	12.80 abd ± 0.05	15.53 cde ± 0.19	16.04 e ± 0.29
2	Gills	11.88 a ± 0.26	12.76 abcd ± 0.62	12.68 abd ± 0.49
2	Gut & gall	11.78 a ± 0.13	*	*
2	Kidney & kidney bone	12.96 abd ± 0.17	*	*
2	Tongue	*	*	16.42 ef ± 0.34
2	Tongue cartilage	*	*	12.06 ab ± 0.09
2	Kidney	*	*	11.16 a ± 0.21
2	Gut	*	*	12.32 ab ± 0.52
2	Intestines	*	*	11.63 a ± 0.36
3	Neck flesh	*	19.05 f ± 0.73	19.58 f ± 0.39
3	Clean head	*	16.96 def ± 0.59	15.31 bcd ± 0.68
3	Jaw	*	18.73 ef ± 0.34	17.21 def ± 0.60
3	Tongue	*	20.18 f ± 0.31	19.06 ef ± 0.44
3	Tongue cartilage	*	14.86 abcde ± 0.71	12.79 abc ± 0.86
3	Gills	*	16.52 def ± 0.99	15.49 cde ± 0.63
3	Gut	*	14.43 bcd ± 0.12	13.94 abcd ± 1.09
3	Intestines	*	*	10.91 a ± 0.18
3	Kidney	*	*	11.74 ab ± 0.31
4	Neck flesh	*	18.49 efg ± 0.36	21.17 gh ± 0.57
4	Clean head	*	16.30 cde ± 0.88	21.49 h ± 0.94
4	Tongue	*	21.70 h ± 0.40	20.67 gh ± 0.49
4	Tongue cartilage	*	17.19 def ± 0.40	16.28 cde ± 0.58
4	Gills	*	16.48 cde ± 0.41	19.38 fgh ± 0.69
4	Gut	*	15.03 cd ± 0.36	14.84 cd ± 0.37
4	Kidney	*	14.48 bcd ± 0.13	11.79 ab ± 0.48
4	Intestines	*	*	10.50 a ± 0.25
4	Heart	*	*	13.51 abc ± 0.07
4	Jaw	*	*	20.04 gh ± 0.36

Means with different letters within each category differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Total Fat

The fat content of both the gut & gall and intestines were significantly higher ($p<0.05$) than the remaining hake head sections within categories (Table 5, detailed results in Appendix 4, Table 1). The fat content of the intestines increased significantly ($p<0.05$) across categories 2-4, which could be attributed to category 4 having the largest hake and that these hake would be the most sexually mature and have the most fat reserves (Table 5). It would be advisable to remove these sections before commercial processing of a food or feed as the susceptibility of the fats to oxidation would decrease the shelf life of the end product dramatically. As expected the jaw and tongue cartilage had the lowest fat content due to bone being the major constituent of these sections.

It was expected that the neck flesh section would have a low fat content as hake muscle is a major constituent of this section (fish muscle having a low fat content). The clean head is also low in fat content due to cartilaginous material being a major part of this section. The fact that both the clean head and jaw in Chapter 4 had a lower average fat content may be attributed to the increased degree of grading and sample size, thus obtaining more reliable results.

Table 5. Statistical differences between average fat content for the respective hake head sections within boat trips for each category as well as across categories.

		Fat content (%)			
		Category			
Boat trip	**Hake head section**	**1**	**2**	**3**	**4**
1	Neck flesh	*	1.29 a ± 0.07	*	*
1	Clean head	*	1.42 a ± 0.15	*	*
1	Jaw	*	1.45 a ± 0.07	*	*
1	Gills	*	2.26 b ± 0.11	*	*
1	Gut & gall	*	5.69 d ± 0.30	*	*
1	Kidney & kidney bone	*	3.11 c ± 0.13	*	*
2	Neck flesh	*	1.01 abc ± 0.04	1.10 abc ± 0.02	0.99 abc ± 0.07
2	Clean head	*	1.11 abc ± 0.05	1.15 abc ± 0.09	1.00 abc ± 0.05
2	Jaw	*	0.81 abc ± 0.01	0.66 a ± 0.02	*
2	Gills	*	1.39 abc ± 0.13	1.15 abc ± 0.11	1.61 c ± 0.43
2	Tongue	*	*	0.93 abc ± 0.01	1.20 abc ± 0.02
2	Tongue cartilage	*	*	0.73 ab ± 0.03	0.86 ab ± 0.04
2	Gut	*	*	1.36 bc ± 0.08	1.19 abc ± 0.10
2	Kidney	*	*	*	2.51 d ± 0.06
3	Neck flesh	0.66 abcd ± 0.02	0.94 cdef ± 0.02	1.14 efgh ± 0.03	0.92 bcde ± 0.05
3	Clean head	0.96 cdef ± 0.04	0.88 abcde ± 0.03	0.96 cdef ± 0.07	1.06 defg ± 0.03
3	Gills	0.78 abcde ± 0.05	0.88 abcde ± 0.09	0.87 abcde ± 0.03	1.15 efgh ± 0.05
3	Gut	1.71 hij ± 0.13	1.53 ghij ± 0.06	1.41 fghi ± 0.15	1.09 defg ± 0.04
3	Jaw	0.83 abcde ± 0.10	0.58 abc ± 0.02	0.49 abc ± 0.03	0.44 a ± 0.01
3	Tongue	*	0.83 abcde ± 0.08	0.87 abcde ± 0.04	0.83 abcde ± 0.02
3	Tongue cartilage	*	0.38 a ± 0.08	0.46 ab ± 0.04	0.44 ab ± 0.02
3	Kidney	*	1.57 ghij ± 0.08	1.98 j ± 0.10	1.79 ij ± 0.12
3	Intestines	*	2.96 k ± 0.16	3.60 l ± 0.28	4.21 m ± 0.08
3	Heart	*	*	*	1.20 defgh ± 0.03

Means with different letters within each boat trip differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Table 6. Statistical differences between average fat content for the respective hake head sections across boat trips within each category.

Fat content (%)

Category	Hake head section		Boat trip	
		1	2	3
2	Neck flesh	1.29 cd ± 0.07	1.01 abcd ± 0.04	0.94 abcd ± 0.02
2	Clean head	1.42 cd ± 0.15	1.11 bcd ± 0.05	0.88 abc ± 0.03
2	Jaw	1.45 cd ± 0.07	0.81 abcd ± 0.01	0.58 ab ± 0.02
2	Gills	2.26 e ± 0.11	1.39 cd ± 0.13	0.88 abc ± 0.09
2	Gut & gall	5.69 g ± 0.30	*	*
2	Kidney & kidney bone	3.11 f ± 0.13	*	*
2	Tongue	*	*	0.83 abc ± 0.08
2	Tongue cartilage	*	*	0.38 a ± 0.08
2	Kidney	*	*	1.57 d ± 0.08
2	Gut	*	*	1.53 d ± 0.06
2	Intestines	*	*	2.96 f ± 0.16
3	Neck flesh	*	1.10 bcd ± 0.02	1.14 bcd ± 0.03
3	Clean head	*	1.15 bcd ± 0.09	0.96 abcd ± 0.07
3	Jaw	*	0.66 ab ± 0.02	0.49 a ± 0.03
3	Tongue	*	0.93 abcd ± 0.01	0.87 abcd ± 0.04
3	Tongue cartilage	*	0.73 abc ± 0.03	0.46 a ± 0.04
3	Gills	*	1.15 bcd ± 0.11	0.87 abcd ± 0.03
3	Gut	*	1.36 cd ± 0.08	1.41 de ± 0.15
3	Intestines	*	*	3.60 f ± 0.28
3	Kidney	*	*	1.98 e ± 0.10
4	Neck flesh	*	0.99 abcd ± 0.07	0.92 abc ± 0.05
4	Clean head	*	1.00 abcd ± 0.05	1.06 abcd ± 0.03
4	Tongue	*	1.20 cde ± 0.02	0.83 abc ± 0.02
4	Tongue cartilage	*	0.87 de ± 0.04	0.45 ab ± 0.02
4	Gills	*	1.61 de ± 0.43	1.15 cde ± 0.05
4	Gut	*	1.19 cde ± 0.10	1.10 bcd ± 0.04
4	Kidney	*	2.51 f ± 0.06	1.79 e ± 0.12
4	Intestines	*	*	4.21 g ± 0.08
4	Heart	*	*	1.20 abcde ± 0.03
4	Jaw	*	*	0.44 a ± 0.01

Means with different letters within each category differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Ash

Table 7 shows the statistical differences between the average ash content for the respective hake head sections within boat trips for each category as well as across categories (Detailed results in Appendix 4, Table 1). In contrast to findings by Braekkan (1958) the majority of the hake head sections differ significantly ($p<0.05$) within and across categories (Table 1). Braekkan (1958) reported the ash content in various sections of male and female *Gadus morhua* (cod), which forms part of the gadoid species (Love, 1988), to be quite similar. These differences could be attributed to several factors namely; different species under investigation, different sections of the fish under investigation, size of fish, state of sexual maturation and seasonal differences. The ash content increased within each respective hake head section from categories 2-4. This was expected as category classification is based on differences in size with category 4 (>80 cm) the biggest and category 1 (30-46 cm) the smallest. This increase in ash content across categories would be more pronounced in hake head sections with more cartilaginous material eg. the jaw section. However, exceptions could occur eg. the gills (small amount of bone present) where the ash content in category 3 is lower than that in category 2.

Both the gut & gall and jaw differed significantly ($p<0.05$) from all the other hake head sections. The jaw had the highest ash content, which is in agreement with earlier findings in Chapter 4 (Figure 4b, 10.98%). It was expected as bone, a collagenous material, constitutes the bulk of this section. As the gut & gall had the lowest ash content, due to lack of bone present, it is therefore assumed that it would be the least likely section to be considered for a potential Ca or P source whereas the jaw would be deemed a very good potential source thereof.

The tongue (0.56%, category 3) had the lowest ash content as was found in Chapter 4. However, the difference in ash content could be attributed to further grading of the hake head into ten sections. One thus expects a decrease in the chemical status within sections as the degree of grading increases.

The ash contents of the sections (>1.30%) that differed significantly ($p<0.05$) across boat trips (Table 8) could be explained by the differences in the sample sizes (number of hake heads) within categories across each boat trip. The second and

Table 7. Statistical differences between average ash content for the respective hake head sections within boat trips for each category as well as across categories.

		Ash content (%)			
		Category			
Boat trip	**Hake head section**	**1**	**2**	**3**	**4**
1	Neck flesh	*	2.27 b ± 0.10	*	*
1	Clean head	*	4.64 d ± 0.16	*	*
1	Jaw	*	9.06 e ± 0.31	*	*
1	Gills	*	3.60 c ± 0.07	*	*
1	Gut & gall	*	1.44 a ± 0.02	*	*
1	Kidney & kidney bone	*	5.25 d ± 0.13	*	*
2	Neck flesh	*	1.62 abc ± 0.16	1.87 bcd ± 0.10	2.73 cde ± 0.13
2	Clean head	*	3.91 fg ± 0.25	4.56 ghi ± 0.16	5.06 hi ± 0.26
2	Jaw	*	7.14 j ± 0.15	8.30 j ± 0.31	*
2	Gills	*	3.12 def ± 0.11	2.44 cde ± 0.26	4.15 fgh ± 0.26
2	Tongue	*	*	0.56 ab ± 0.02	0.91 ab ± 0.03
2	Tongue cartilage	*	*	3.57 efg ± 0.17	5.31 i ± 0.44
2	Gut	*	*	0.60 a ± 0.02	0.84 ab ± 0.02
2	Kidney	*	*	*	1.29 ab ± 0.02
3	Neck flesh	3.19 b ± 0.12	4.00 bc ± 0.18	4.77 cdef ± 0.36	4.48 cde ± 0.21
3	Clean head	4.21 bc ± 0.14	5.62 efgh ± 0.21	5.71 efgh ± 0.30	6.17 gh ± 0.34
3	Gills	4.34 bcd ± 0.17	4.94 cdefg ± 0.32	6.44 h ± 0.28	5.51 defgh ± 0.08
3	Gut	0.86 a ± 0.03	0.80 a ± 0.02	0.76 a ± 0.05	0.90 a ± 0.02
3	Jaw	10.18 i ± 0.28	10.36 ij ± 0.36	11.51 j ± 0.11	14.76 k ± 0.34
3	Tongue	*	0.83 a ± 0.03	0.83 a ± 0.03	0.90 a ± 0.02
3	Tongue cartilage	*	6.19 gh ± 0.30	5.92 fgh ± 0.34	6.71 h ± 0.24
3	Kidney	*	1.73 a ± 0.56	1.23 a ± 0.05	1.30 a ± 0.02
3	Intestines	*	1.68 a ± 0.07	1.08 a ± 0.03	1.20 a ± 0.01
3	Heart	*	*	*	1.01 a ± 0.03

Means with different letters within each boat trip differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

Table 8: The comparison between the average ash content present in each hake head section per category across boat tips 1-3. Separate analysis were done for each category, which is separated by a line.

		Ash content (%)		
		Boat trip		
Category	**Hake head section**	**1**	**2**	**3**
2	Neck flesh	2.27 bc ± 0.10	1.62 ab ± 0.16	4.00 def ± 0.18
2	Clean head	4.64 efg ± 0.16	3.91 def ± 0.25	5.62 gh ± 0.21
2	Jaw	9.06 j ± 0.31	7.14 i ± 0.15	10.36 k ± 0.36
2	Gills	3.60 de ± 0.07	3.12 cd ± 0.11	4.94 fgh ± 0.32
2	Gut & gall	1.44 ab ± 0.02	*	*
2	Kidney & kidney bone	5.25 gh ± 0.13	*	*
2	Tongue	*	*	0.83 a ± 0.03
2	Tongue cartilage	*	*	6.19 hi ± 0.30
2	Kidney	*	*	1.73 abc ± 0.56
2	Gut	*	*	0.80 a ± 0.02
2	Intestines	*	*	1.68 abc ± 0.07
3	Neck flesh	*	1.87 bc ± 0.10	4.77 ef ± 0.36
3	Clean head	*	4.56 e ± 0.16	5.71 fg ± 0.30
3	Jaw	*	8.30 h ± 0.31	11.51 i ± 0.11
3	Tongue	*	0.56 ab ± 0.02	0.83 ab ± 0.03
3	Tongue cartilage	*	3.57 de ± 0.17	5.92 g ± 0.34
3	Gills	*	2.44 cd ± 0.26	6.44 g ± 0.28
3	Gut	*	0.60 a ± 0.02	0.76 ab ± 0.05
3	Intestines	*	*	1.08 ab ± 0.03
3	Kidney	*	*	1.23 abc ± 0.05
4	Neck flesh	*	2.73 b ± 0.13	4.48 cd ± 0.21
4	Clean head	*	5.06 cde ± 0.26	6.17 ef ± 0.34
4	Tongue	*	0.91 a ± 0.03	0.90 a ± 0.02
4	Tongue cartilage	*	5.31 de ± 0.44	6.71 f ± 0.24
4	Gills	*	4.15 c ± 0.26	5.51 de ± 0.08
4	Gut	*	0.84 a ± 0.02	0.90 a ± 0.02
4	Kidney	*	1.29 a ± 0.02	1.30 a ± 0.02
4	Intestines	*	*	1.18 a ± 0.01
4	Heart	*	*	1.01 a ± 0.03
4	Jaw	*	*	14.76 g ± 0.34

Means with different letters within each category differ significantly ($p<0.05$). *Insufficient sample for chemical analysis.

third boat trips were executed during the Cape hake main spawning season whereas the first boat trip was executed during the secondary spawning season. This could also have been another contributing factor.

Minerals

Figures 1 and 2 respectively show the macro and trace elements present in each of the hake head sections of category 2, boat trip 1. The jaw section had the highest amount of Ca present as expected due to the fact that calcified bone material is a major constituent of this section. Similarly, other sections (clean head, tongue cartilage, gills, gill covers and kidney & kidney bone) with a certain degree of cartilaginous material present also showed a similar trend of considerable amounts of Ca present. These results corroborate the findings reported by other workers (Paul & Southgate, 1978; Navarro, 1991; Martínez-Valverde, 2000). The amounts of Na, Mg and K were negligible in the respective hake heads.

The neck flesh, jaw, gills, kidney & kidney bone and the gut & gall contain considerable amounts of Fe followed by Zn compared to the other trace elements. The low amounts of Cu present confirms earlier results (Paul & Southgate, 1978; Navarro, 1991; Martínez-Valverde, 2000).

Figures 3-7 show the amount of the macro elements present in categories 1-4 of each hake head section sampled during the second boat trip, respectively. There were little difference in P content between categories within each respective section except in the case of the jaw and tongue cartilage due to bone being a major constituent of these sections (Figure 3). The few differences in K content observed across categories within each section could be attributed to experimental error (Figure 4). The different macro and mineral concentrations observed for Ca, Mg and Na across categories, could be ascribed to difference in hake size, which were similar to that observed for P content. From the results obtained both the jaw and tongue cartilage are ideal sources of P, K, Ca and Na.

Figures 8-11 show each of the trace elements investigated for categories 1-4 for each hake head section sampled during the second boat trip, respectively. In Figures 8-10 one can see that the tongue had the highest amount of Cu, Zn and Pb

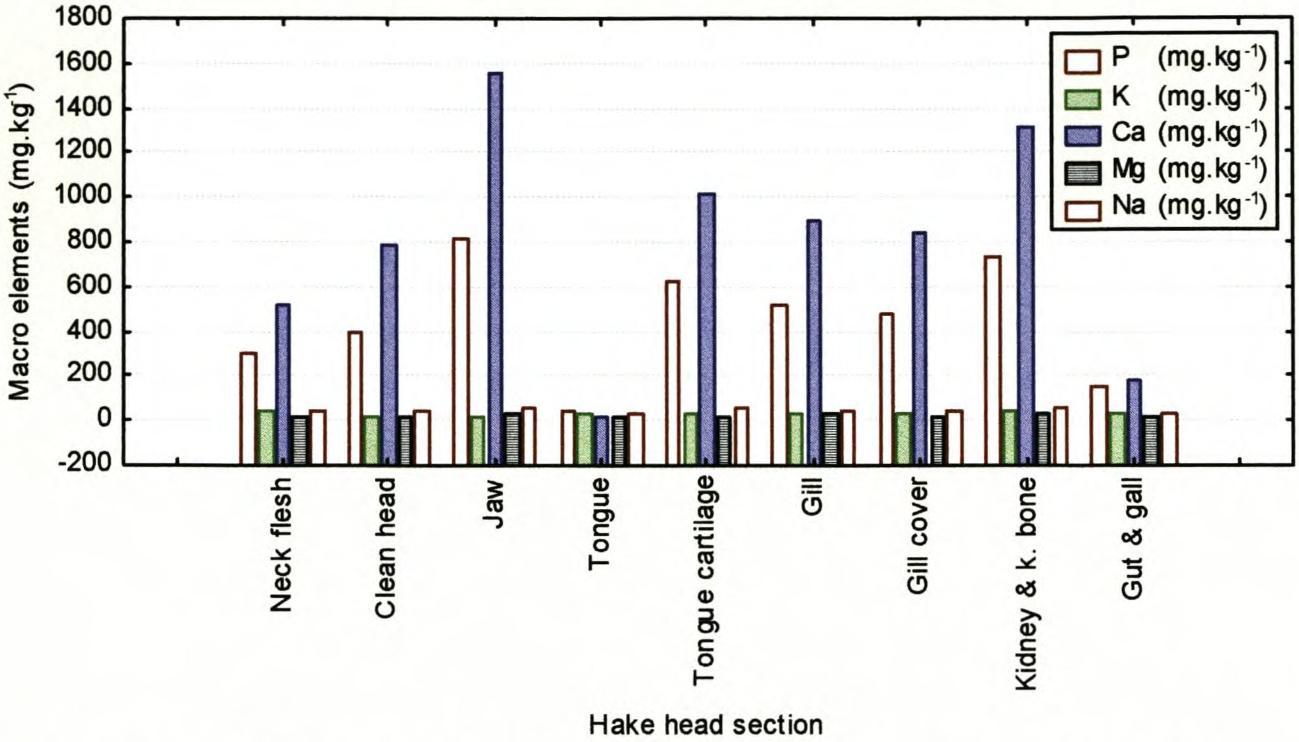

Figure 1. The phosphorous, potassium, calcium, magnesium and sodium (mg.kg^{-1}) present in each of hake head section of category 2 for the first boat trip.

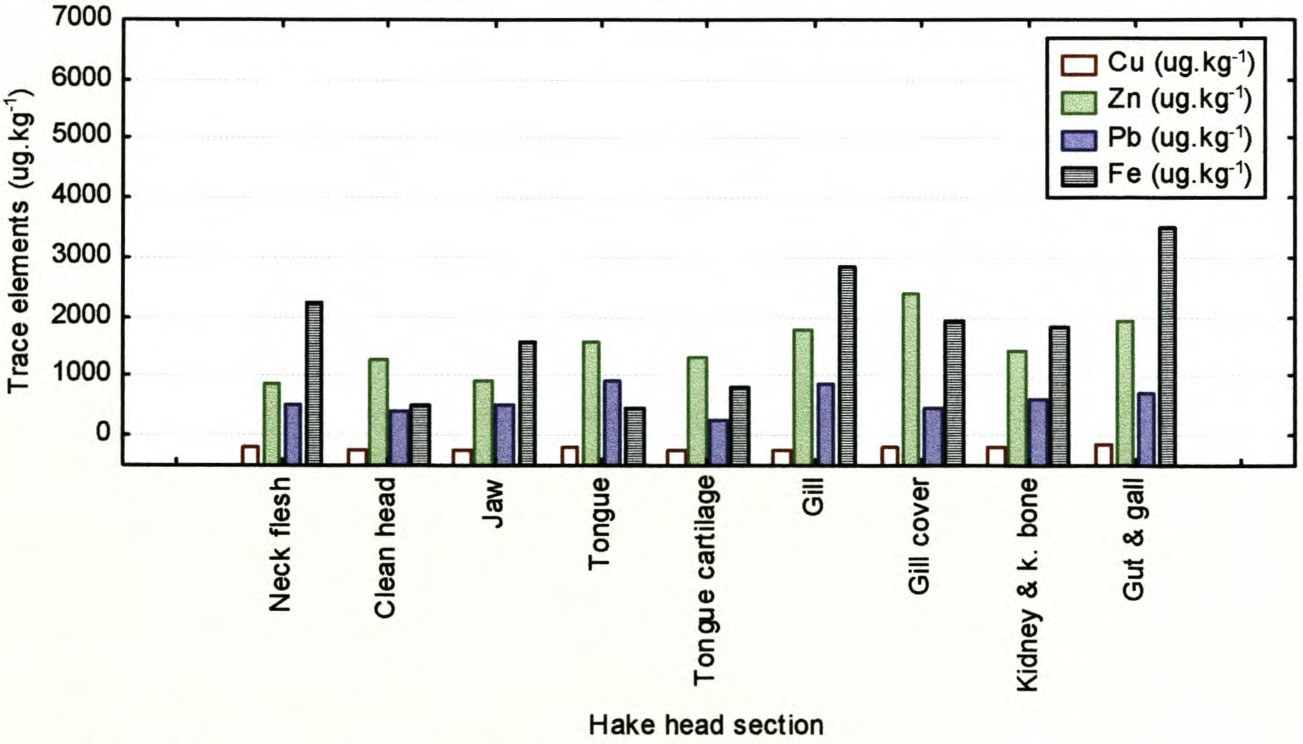

Figure 2. The amount of copper, zinc, lead and iron (µg.kg^{-1}) present in each hake head section of category 2 for the first boat trip.

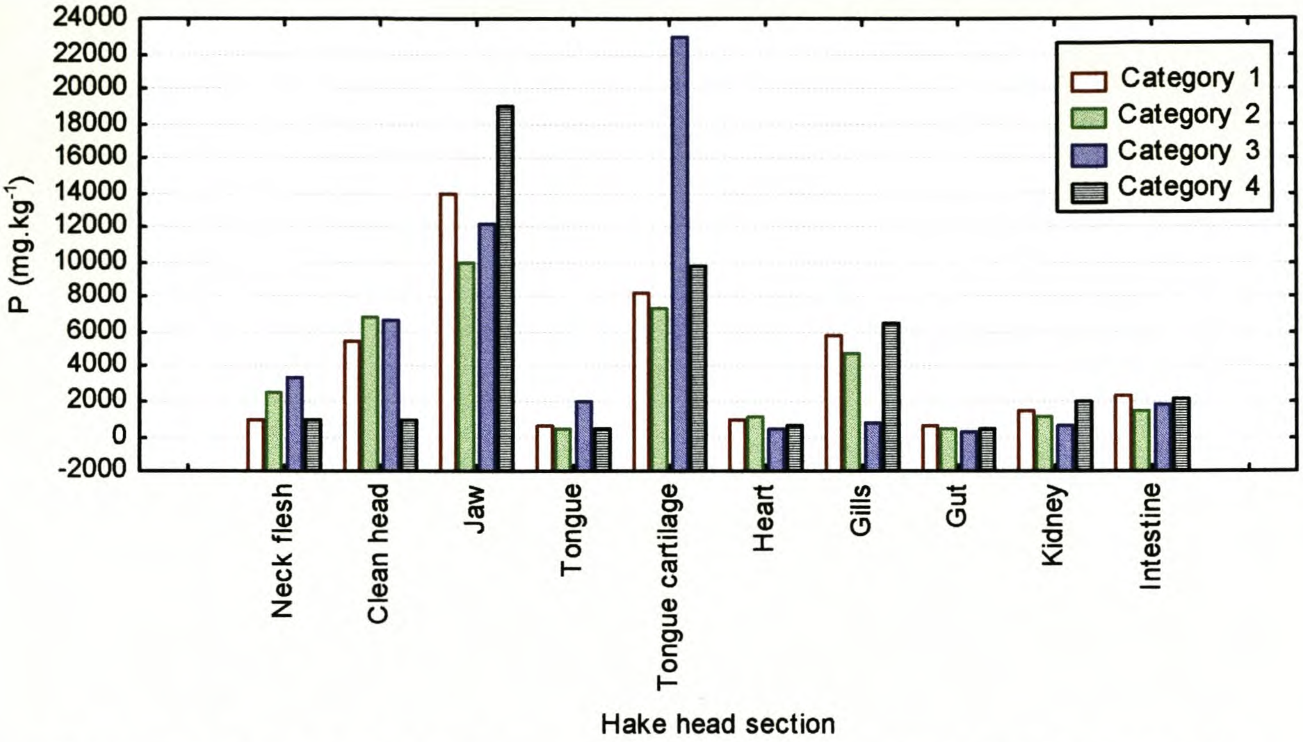

Figure 3. The amount of phosphorous (mg.kg^{-1}) present in each hake head section per category for the second boat trip.

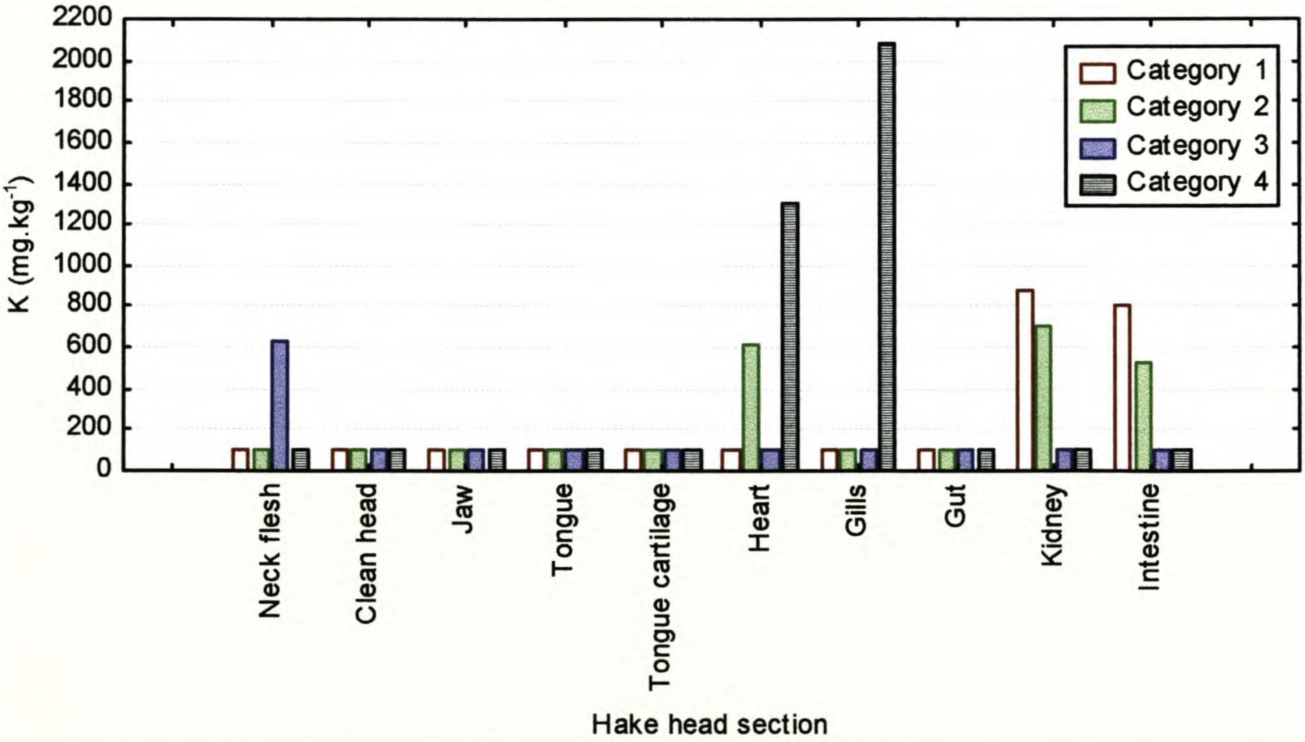

Figure 4. The amount of potassium (mg.kg^{-1}) present in each hake head section per category for the second boat trip.

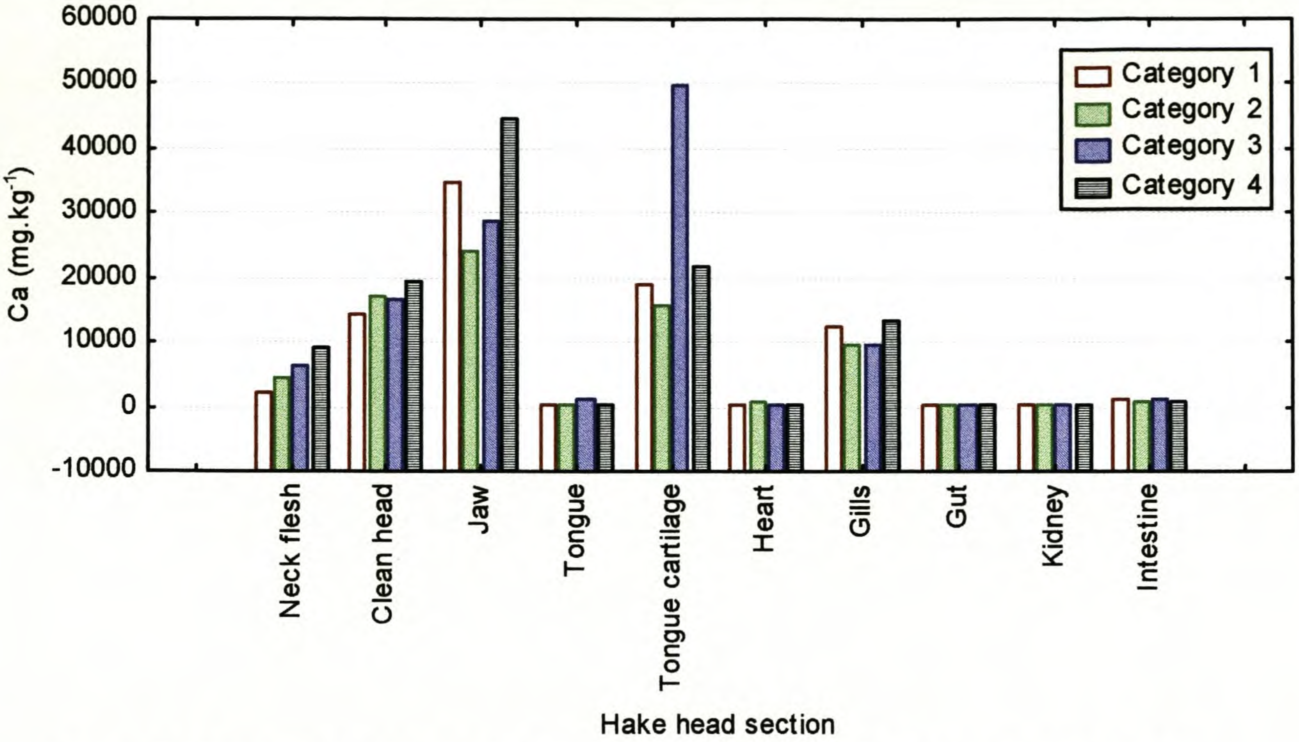

Figure 5. The amount of calcium (mg.kg^{-1}) present in each hake head section per category for the second boat trip.

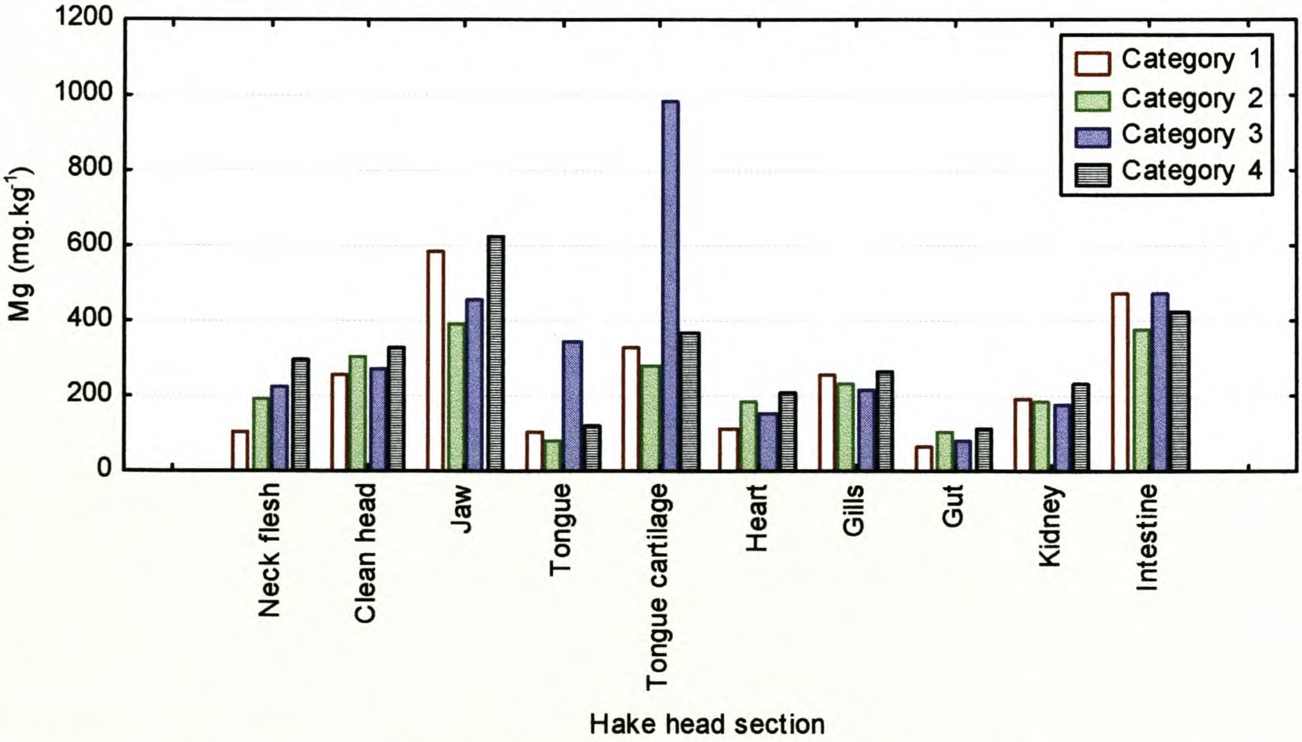

Figure 6. The amount of magnesium (mg.kg^{-1}) present in each hake head section per category for the second boat trip.

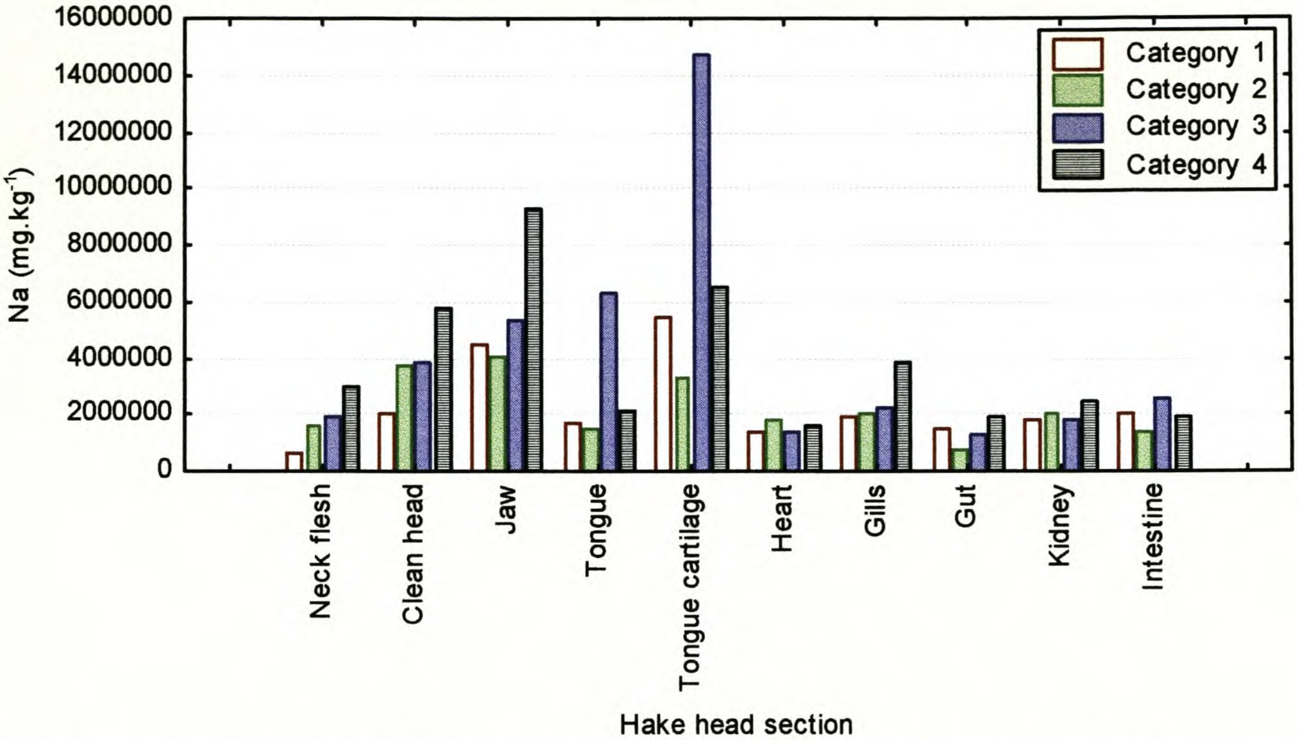

Figure 7. The amount of sodium (mg.kg^{-1}) present in each hake head section per category for the second boat trip.

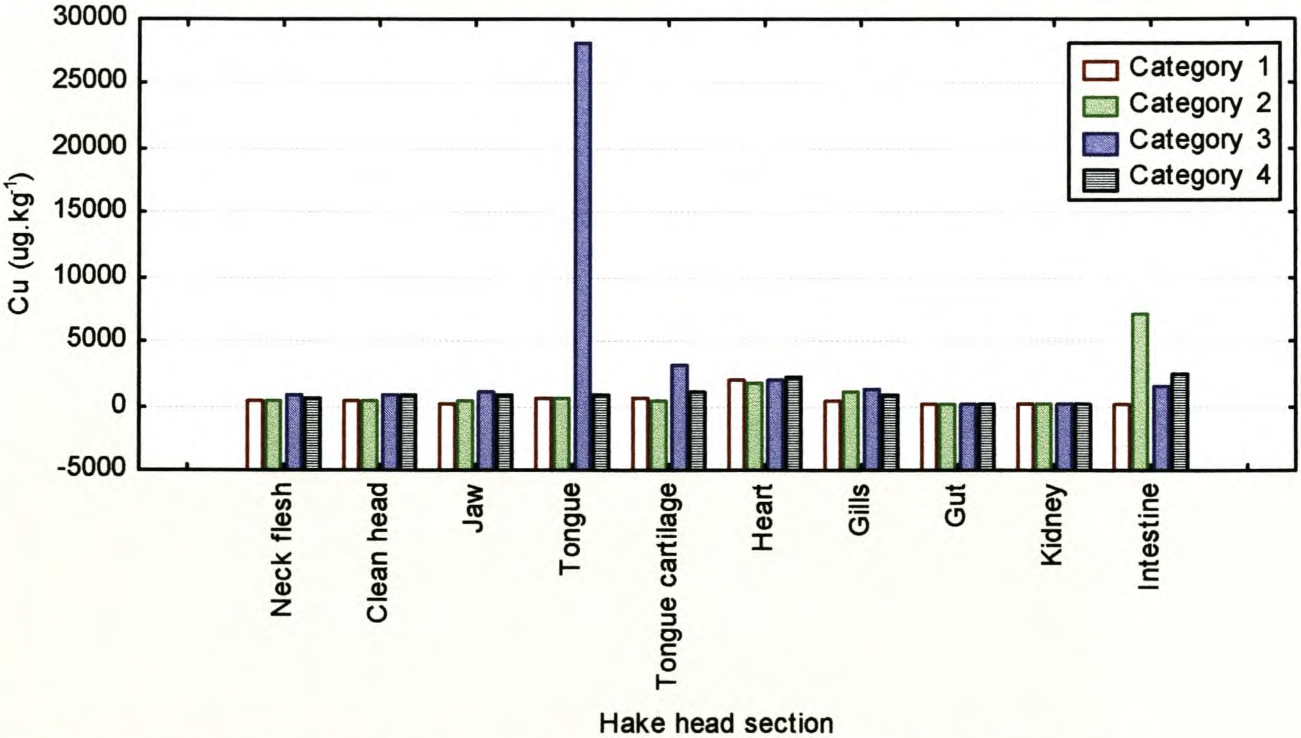

Figure 8. The amount of copper (µg.kg^{-1}) present in each hake head section per category for the second boat trip.

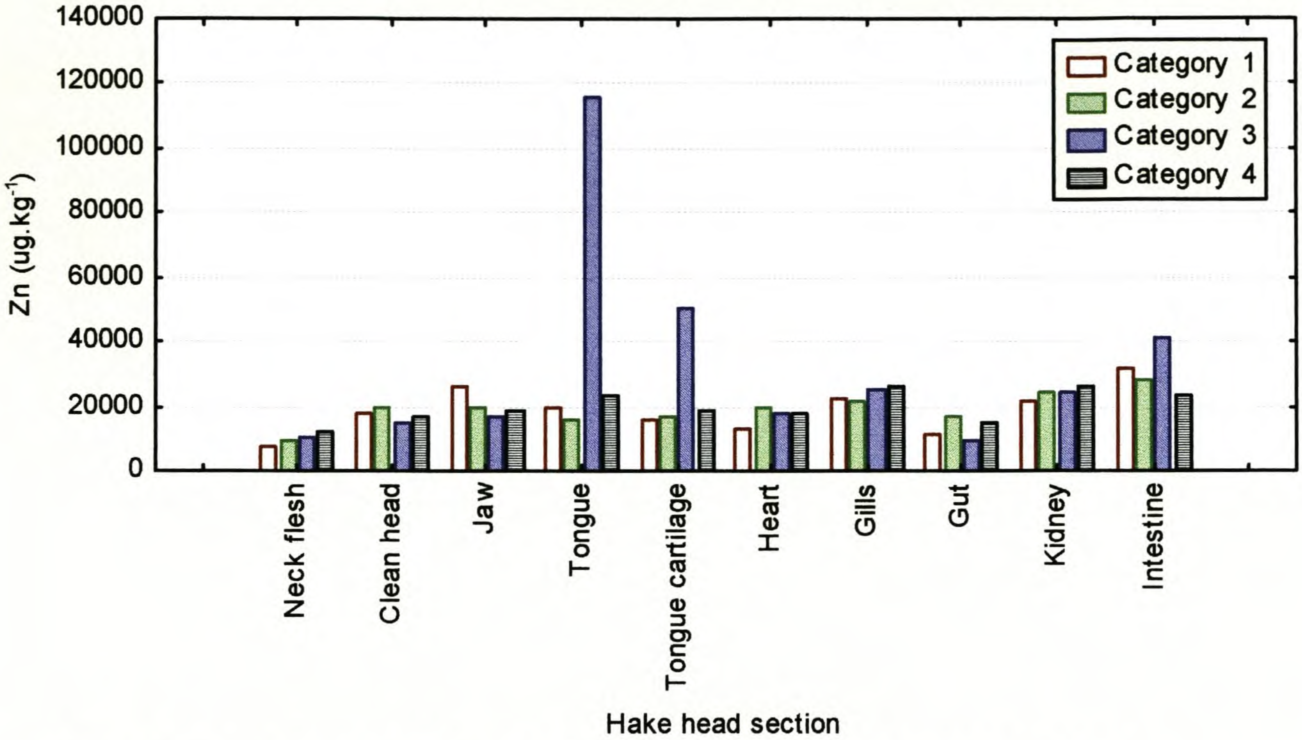

Figure 9. The amount of zinc (μg.kg^{-1}) present in each hake head section per category for the second boat trip.

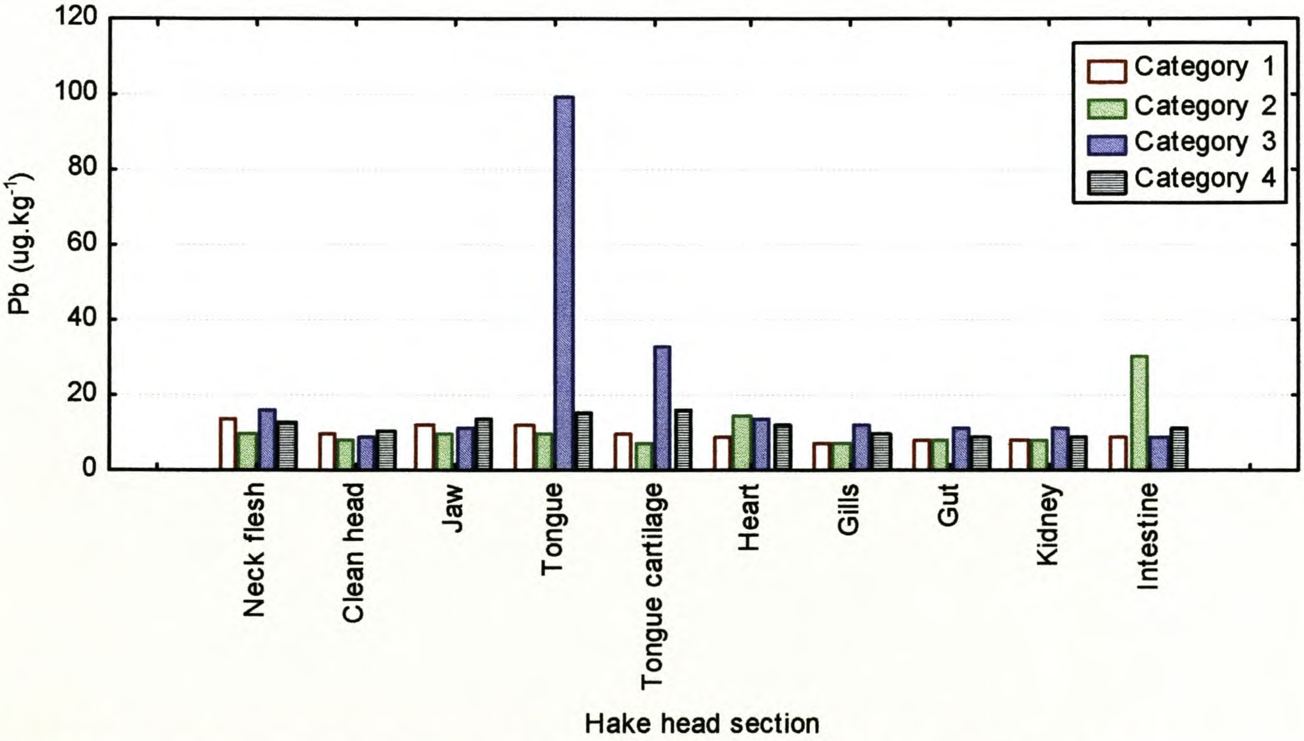

Figure 10. The amount of lead (μg.kg^{-1}) present in each hake head section per category for the second boat trip.

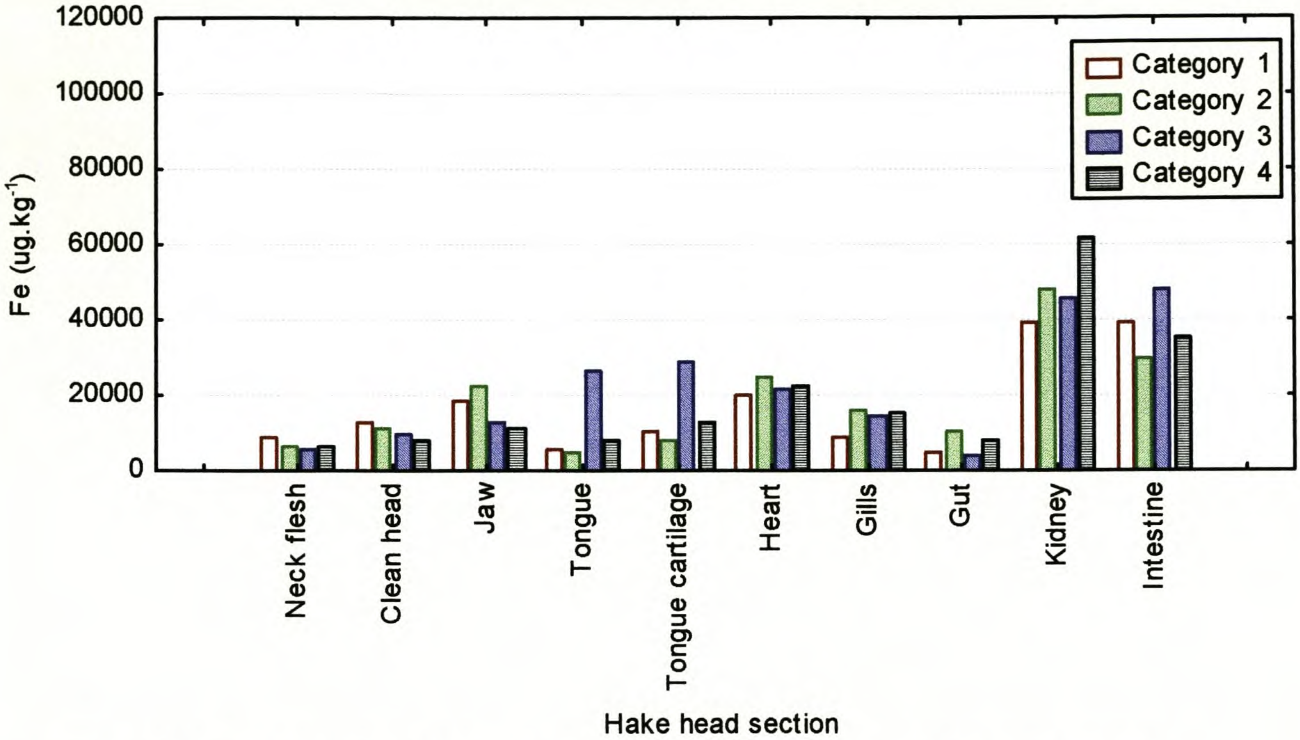

Figure 11. The amount of iron (μg.kg^{-1}) present in each hake head section per category for the second boat trip.

present as opposed to the other sections. Similarly, the tongue cartilage also had considerable amounts of Zn and Pb. The intestines (category 2) also had considerable amounts of Pb present (Figure 10). The amount of Cu, Zn and Pb present in each of the remaining hake head sections were negligible. In Figure 6 the kidney and intestines were the only two sections, which had considerable amounts of Fe present.

Chemical composition and fatty acid profile of the clean head and neck flesh sections

Chemical composition

Figures 12 to 15 show the chemical composition (moisture, protein, fat and ash) for each of the four categories for both the neck flesh and clean head sections (boat trip 3). Only in the case of the ash content did the clean head and neck flesh sections differ significantly ($p<0.05$). This can be attributed to the fact that the clean head contains more calcified bone whereas the neck flesh consists mainly of hake muscle. No significant differences ($p>0.05$) occurred across categories.

Figure 12, showed that it was only the moisture content of category 4 clean head (78.80%) and category 1 neck flesh (82.41%) which differed significantly ($p<0.05$). In general all the categories in both the clean head (81.40, 80.19, 80.62 & 78.80% for categories 1-4, respectively) and neck flesh (82.41, 79.85, 81.37 & 81.56% for categories 1-4, respectively) had relatively high average moisture percentages present. This confirmed previous results (Table 3). Within the clean head there was a decrease in the moisture content from categories 1-4 as was expected due to the presence of calcified bone and the increase in the size of the fish.

Figure 13 shows the protein content within each of the four categories for both the clean head (13.58, 15.36, 13.71 & 16.44% for categories 1-4, respectively) and neck flesh (15.77, 18.22, 16.79 & 17.56% for categories 1-4, respectively). In Table 5 it can be seen that it was only category 4 clean head and category 2 neck flesh sampled during the second boat trip, which correlated with those respective categories mentioned earlier. The differences concerning the remaining categories and boat trips could be due to factors already mentioned. In neither of the hake head sections were there a decreasing or increasing phenomenon within each of the respective categories. Category 2 neck flesh (18.22%) had the highest average protein percentage whereas category 1 clean head (13.58%) had the lowest. The four categories for each of the clean head and neck flesh showed no significant differences ($p<0.05$) between them. Categories 1 and 3 of the clean head, however, differed significantly ($p<0.05$) from categories 2 and 4 of the neck flesh. There were no significant differences ($p>0.05$) in the fat content across categories for both the clean head and neck flesh sections.

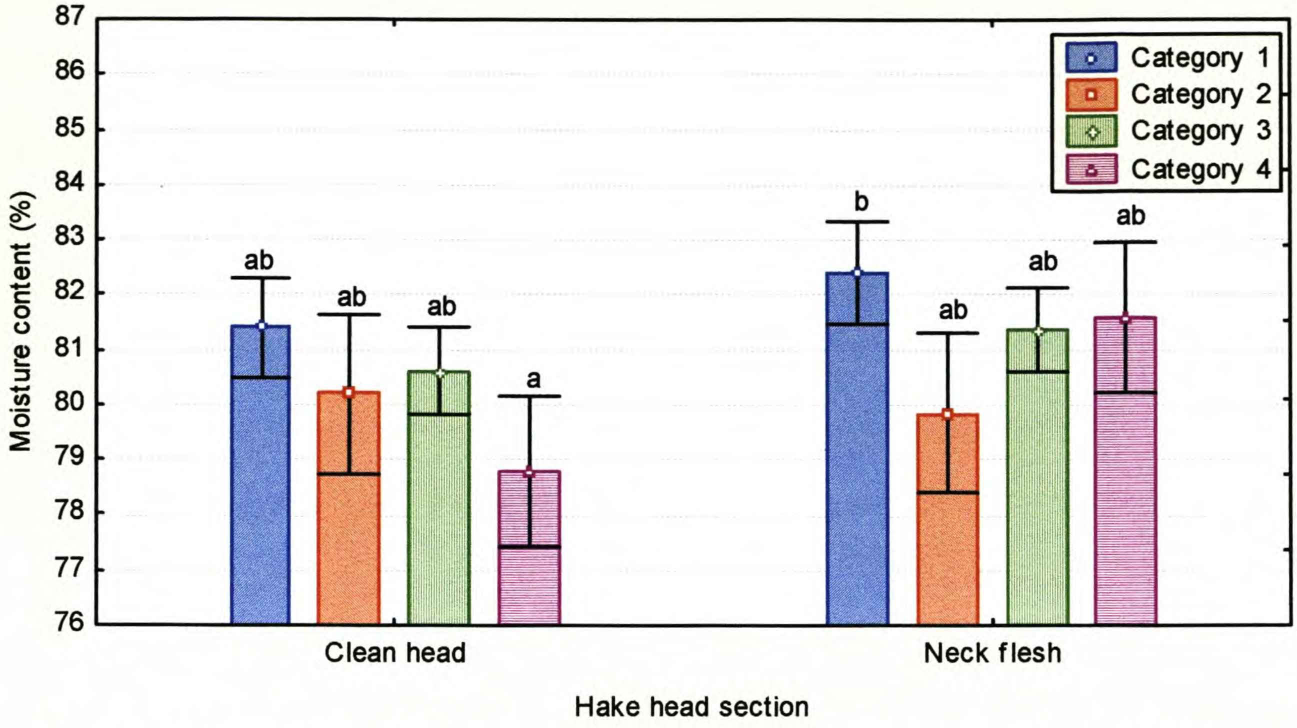

Figure 12. The percentage moisture in the clean head and neck flesh sections per category. (Averages with different letters differ significantly ($p<0.01$)).

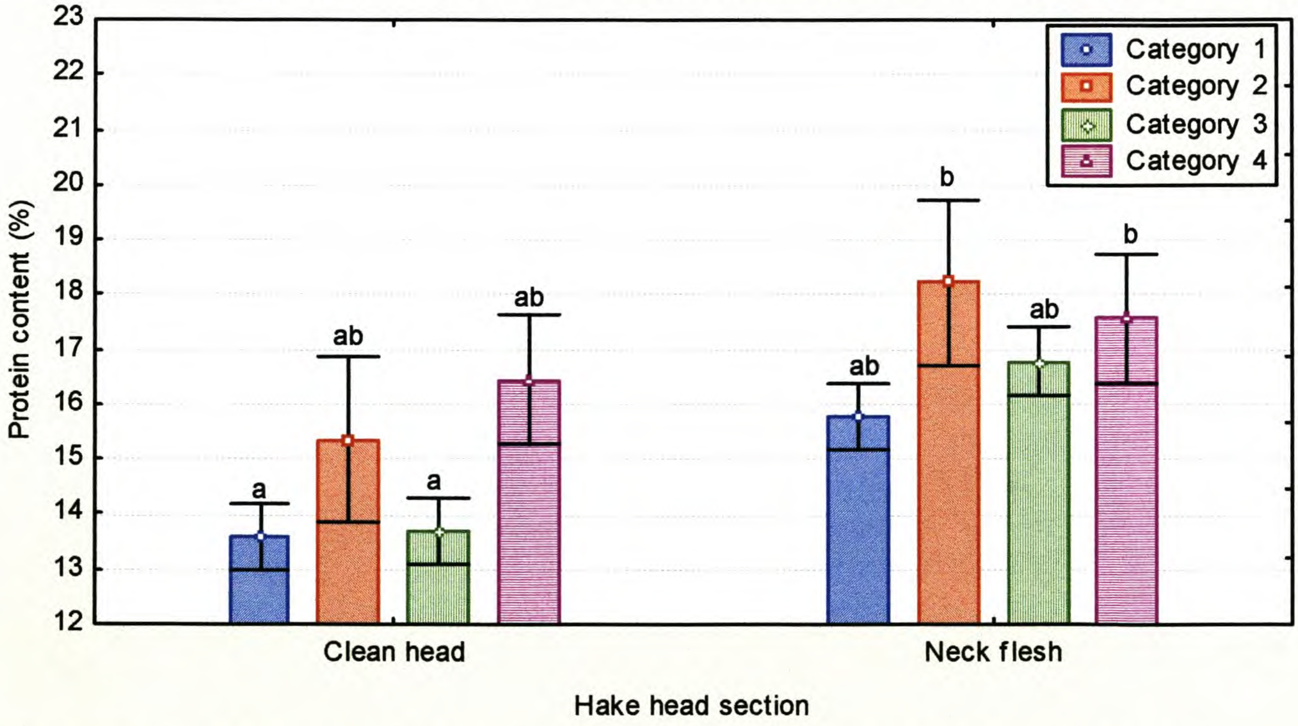

Figure 13. The percentage protein in the clean head and neck flesh sections per category. (Averages with different letters differ significantly ($p<0.01$)).

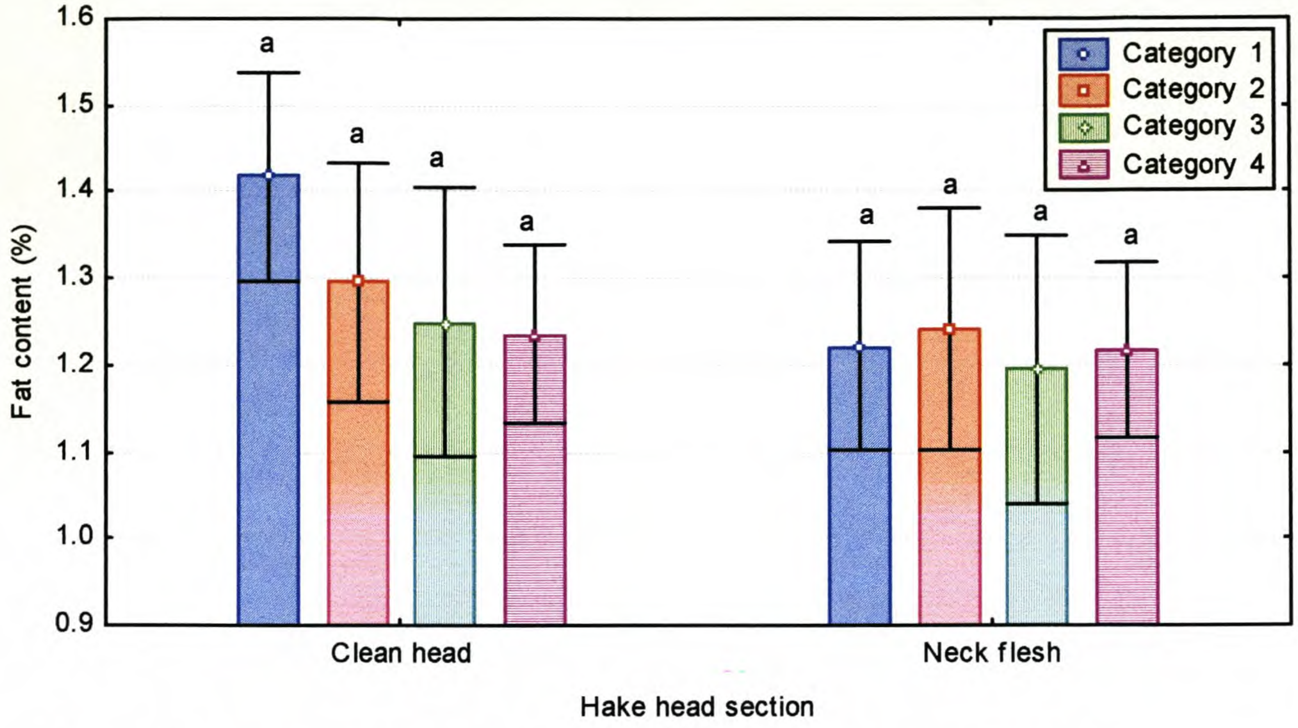

Figure 14. The percentage fat in the clean head and neck flesh sections per category. (Averages with different letters differ significantly ($p<0.01$)).

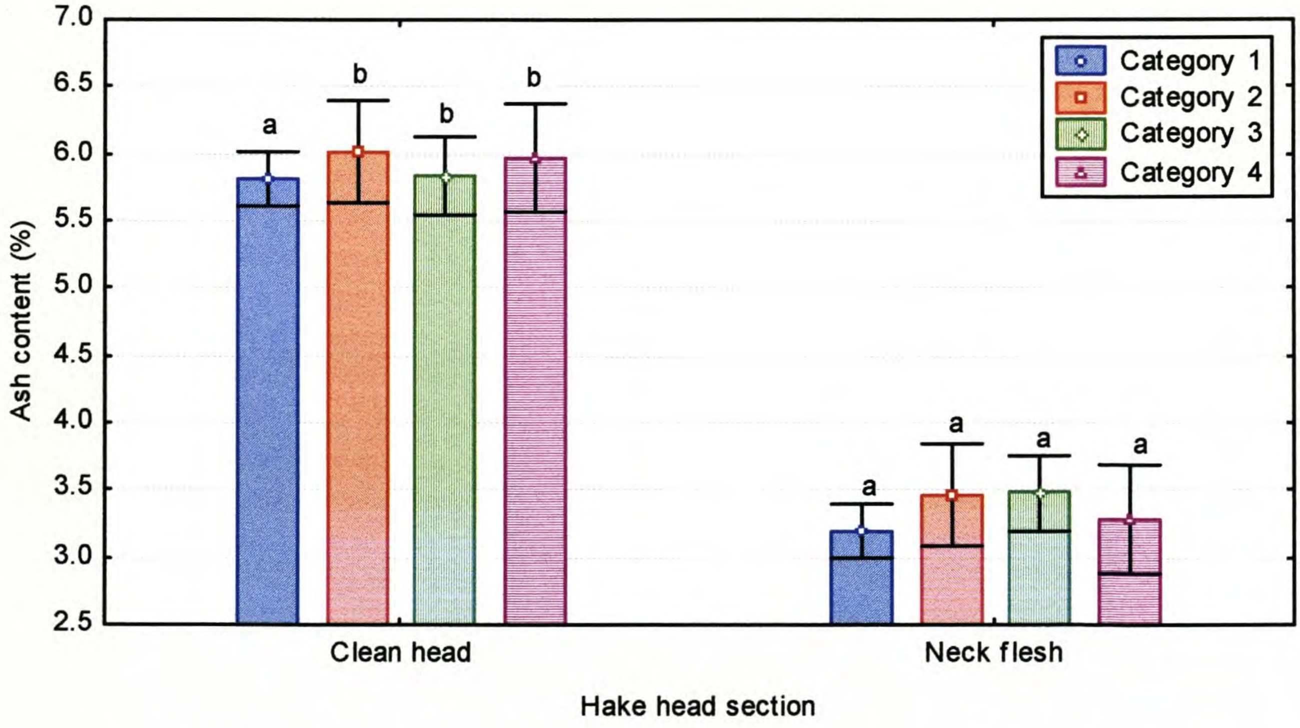

Figure 15. The percentage ash in the clean head and neck flesh sections per category. (Averages with different letters differ significantly ($p<0.01$)).

Figures 16-20 show the macro elements (P, K, Ca, Mg & Na) present in the clean head and neck flesh for each of the four categories. Apart from the K content the clean head had a higher P, Ca, Mg and Na content than the neck flesh.

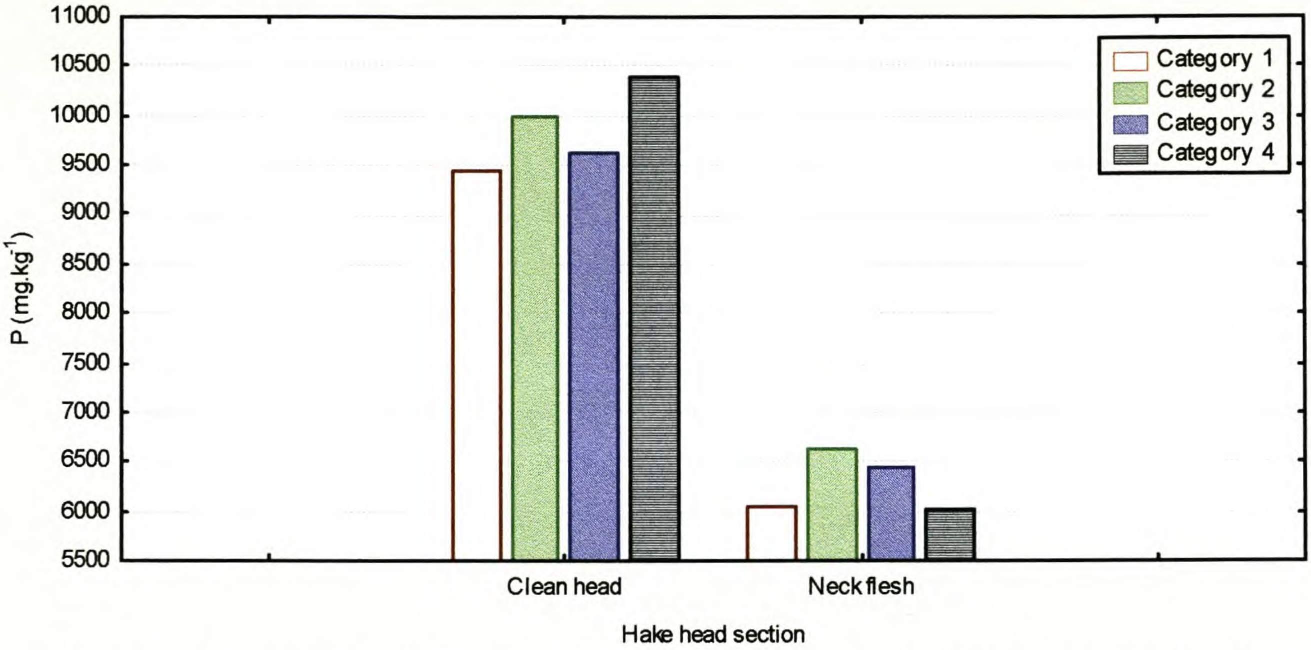

Figure 16. The amount of phosphorous (mg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

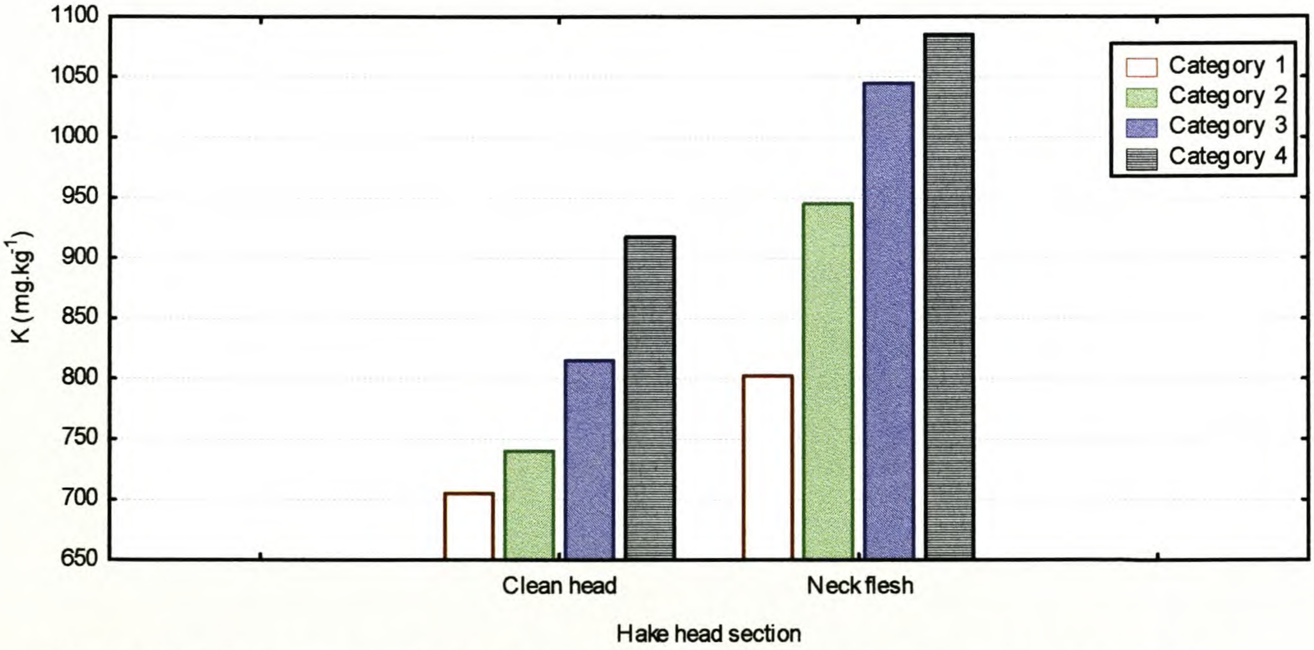

Figure 17. The amount of potassium (mg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

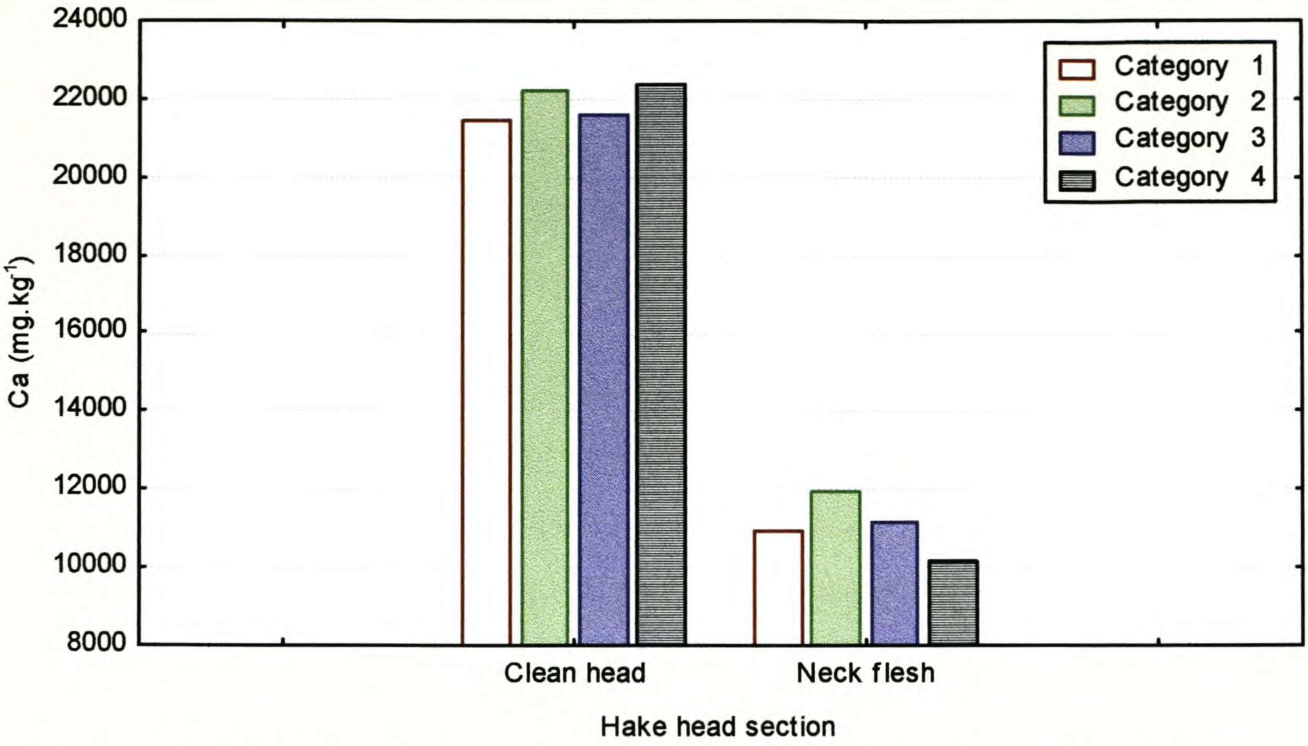

Figure 18. The amount of calcium (mg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

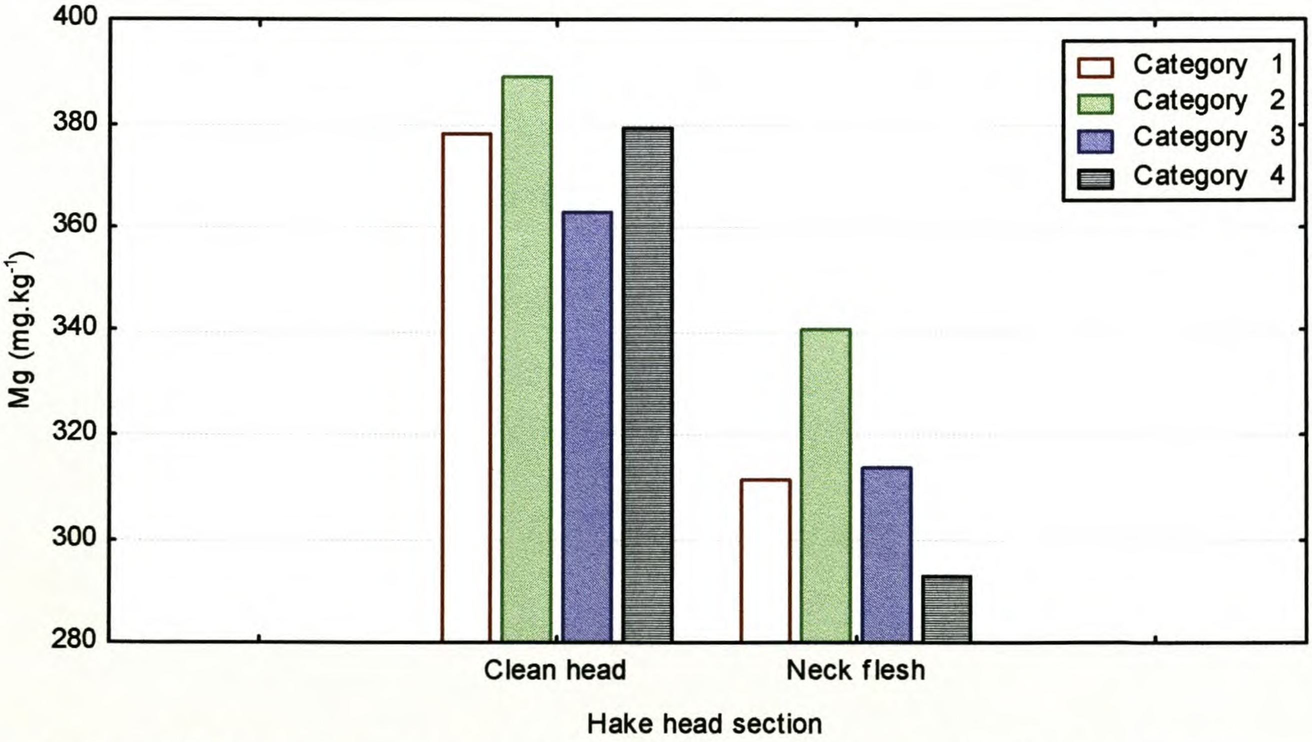

Figure 19. The amount of magnesium (mg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

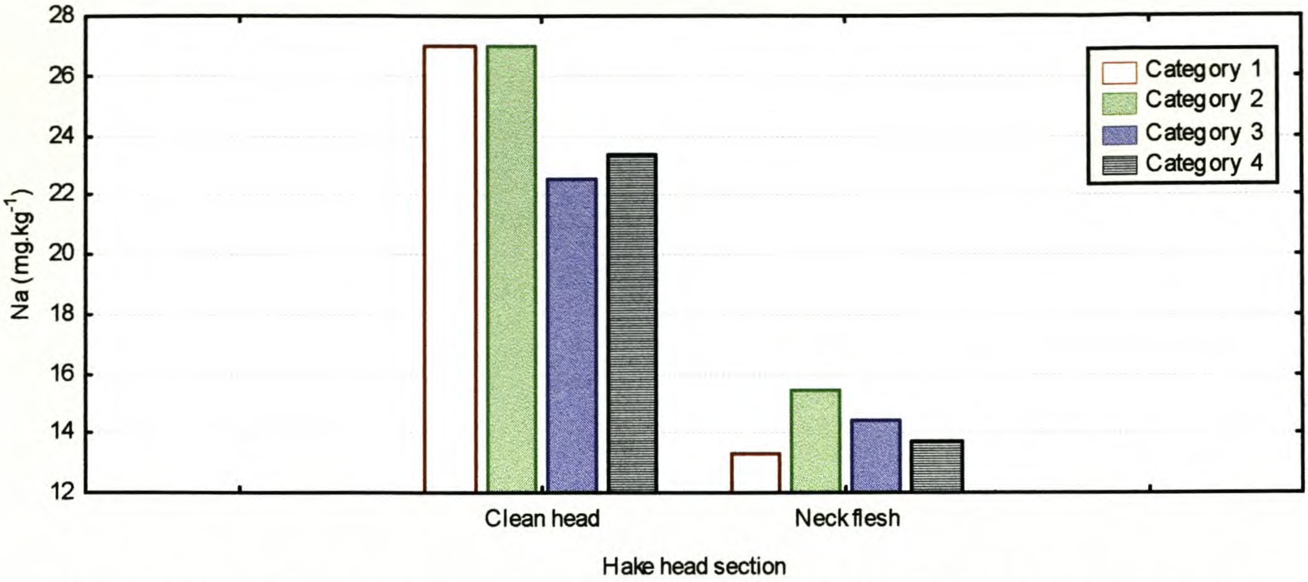

Figure 20. The amount of sodium (mg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

Figures 21-24 showed the amount of each of the trace elements (Cu, Zn, Pb & Fe) present in the clean head and neck flesh for each of the four categories. The clean head and neck flesh had similar Fe and Cu contents whereas the clean head was higher in Zn and the neck flesh higher in Pb. The high Pb content present could be due to the accumulation of toxic components from the sea water with the neck flesh content being higher due to hake muscle constituting a major part of this section.

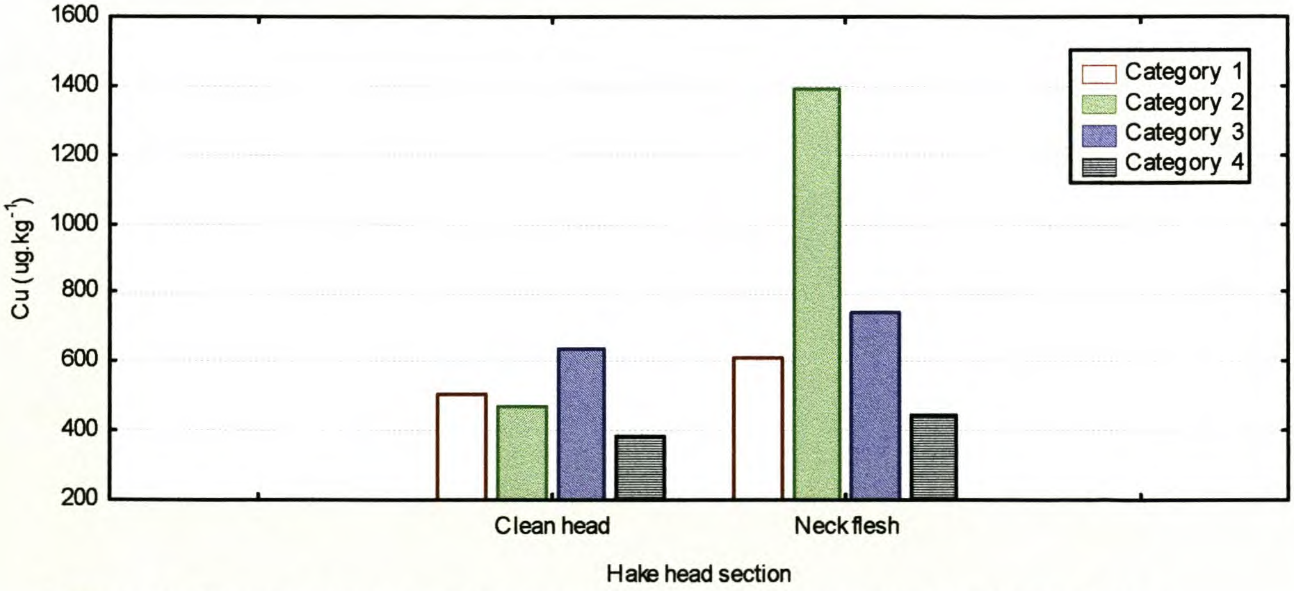

Figure 21. The copper (µg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

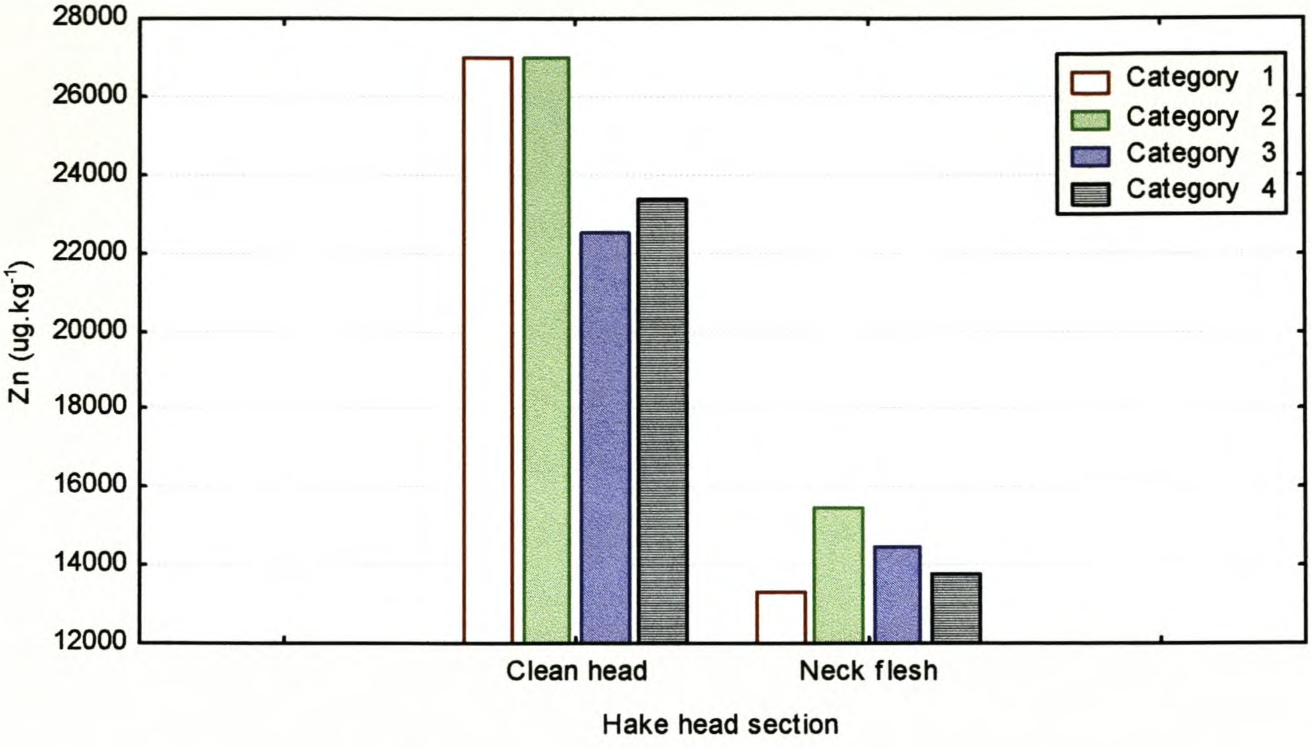

Figure 22. The zinc (µg.kg^{-1}) present in both the clean head and neck flesh sections each of the four categories.

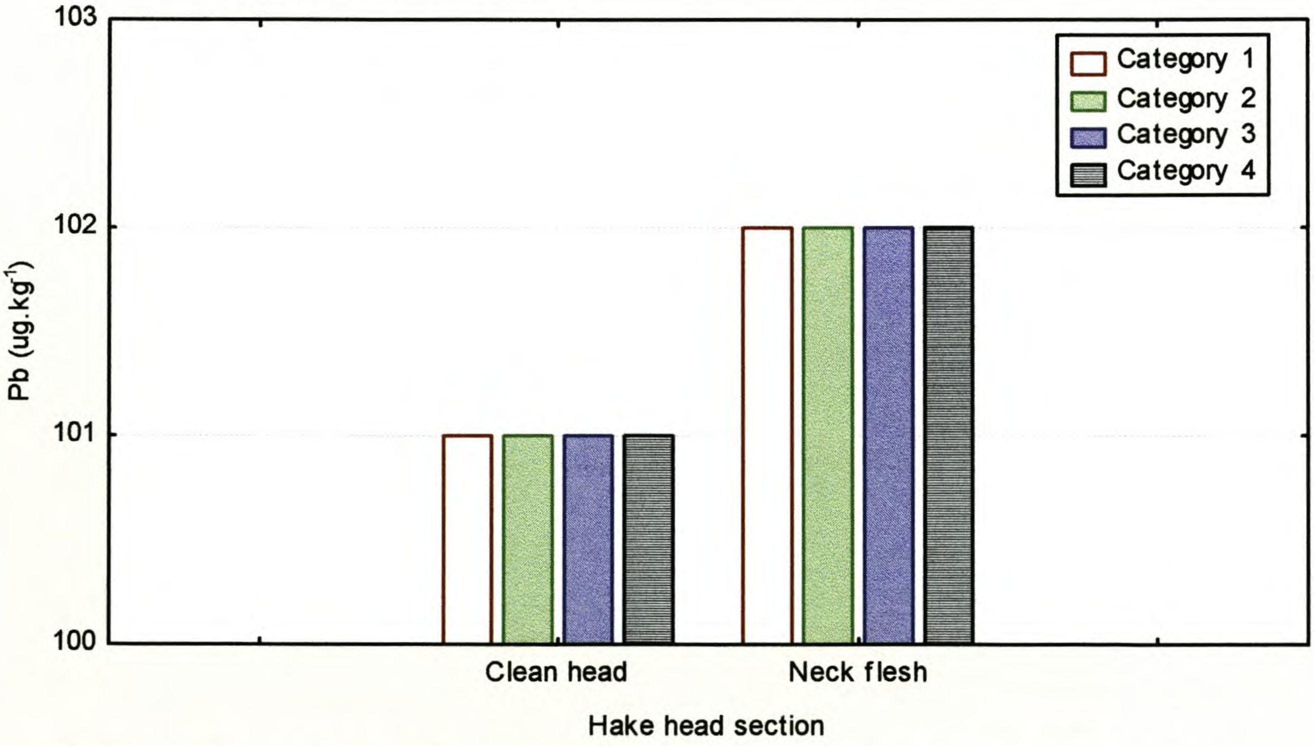

Figure 23. The lead (µg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

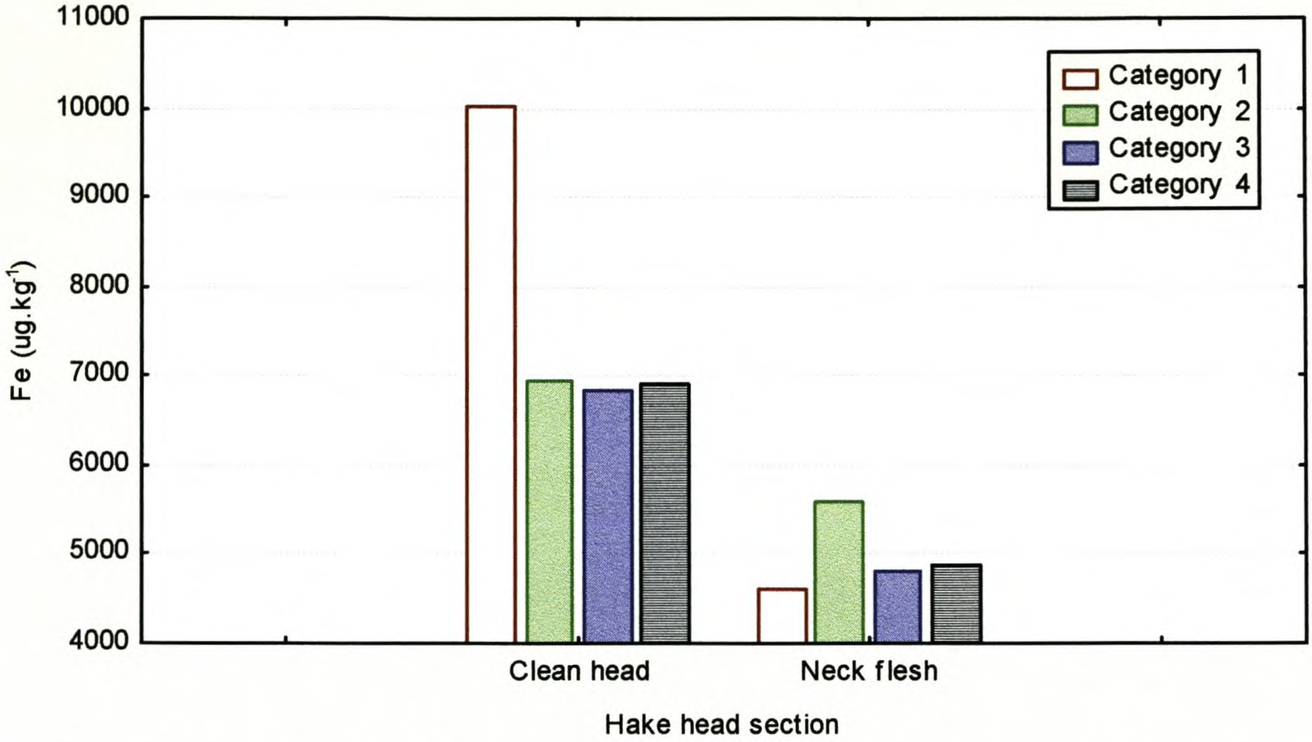

Figure 24. The iron (µg.kg^{-1}) present in both the clean head and neck flesh sections for each of the four categories.

Fatty acid status of clean head & neck flesh

Figures 25-28 show the change in n-3 fatty acid content over a six day period for the clean head section for all categories, respectively. As expected the docosahexaenoic acid (C22:6n3; DHA) was the most prominent fatty acid in the clean head section. α-Linolenic (C18:3n3), eicosatrienoic (C20:3n3) and docosapentaenoic (C22:5n3) acid were found to be present in negligible amounts. An inverse relationship between DHA and EPA was observed in Figures 25-28.

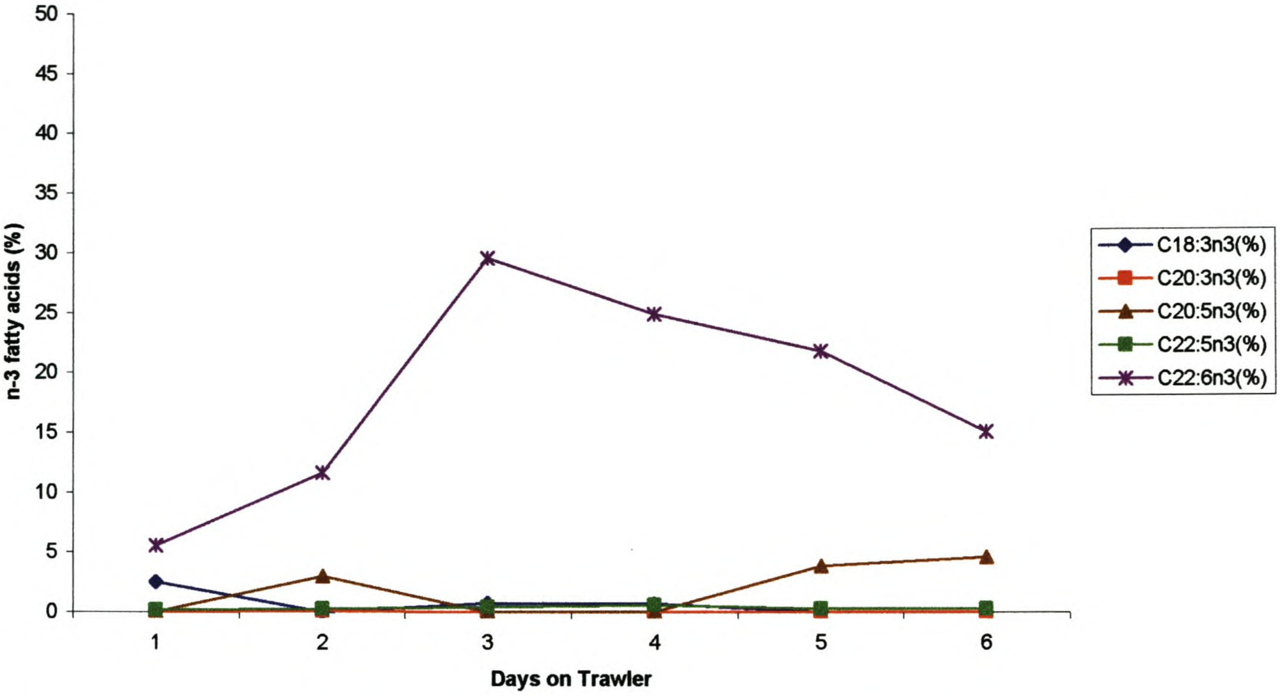

Figure 25. Change in percentage n-3 fatty acids of category 1 clean head sections over a period of six days.

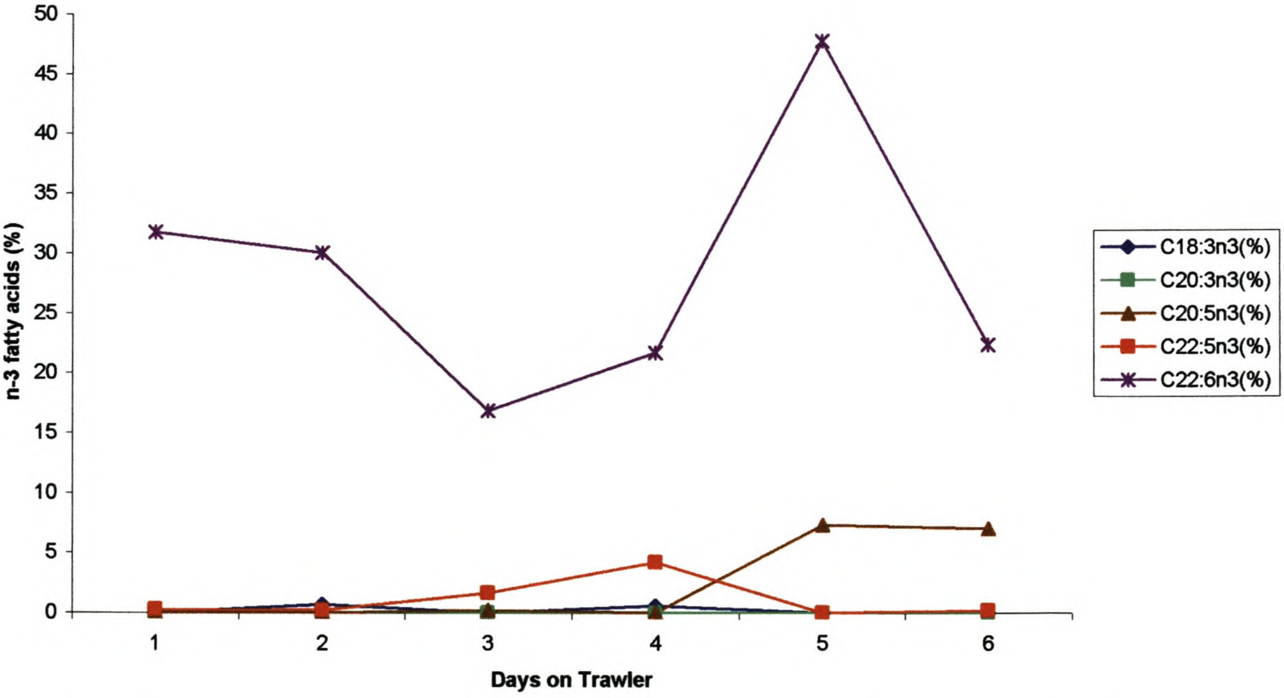

Figure 26. Change in percentage n-3 fatty acids of category 2 clean head sections over a period of six days.

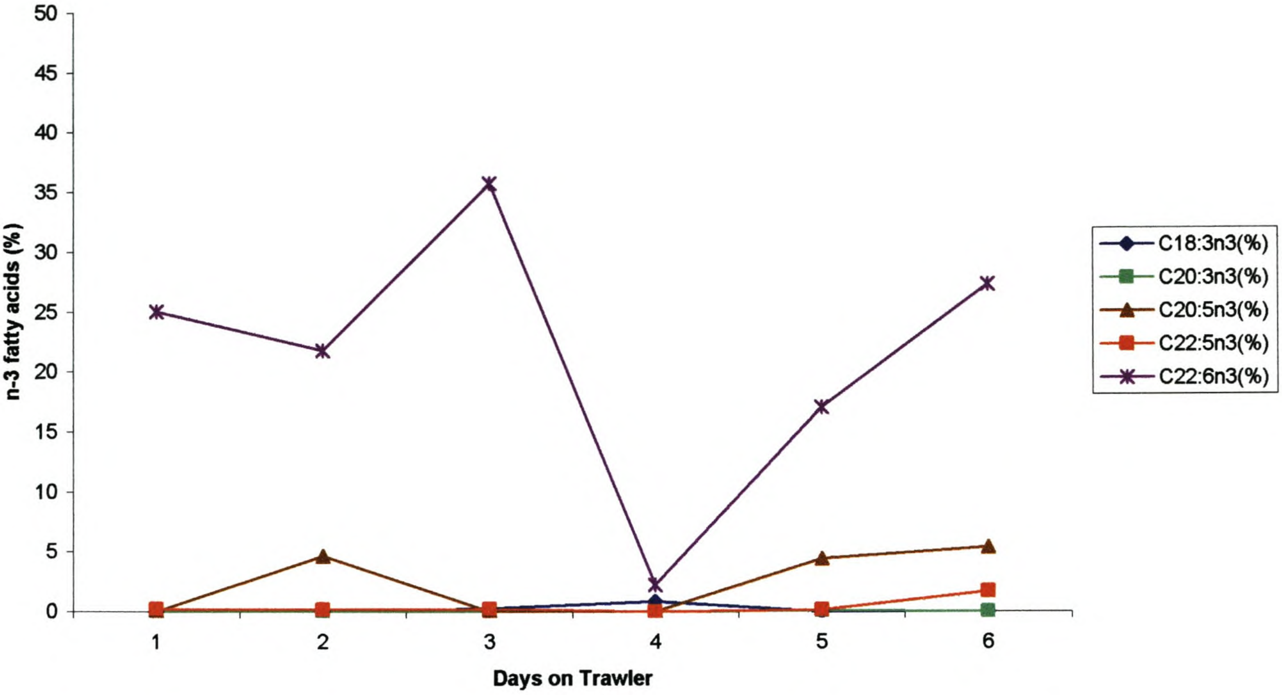

Figure 27. Change in percentage n-3 fatty acids of category 3 clean head sections over a period of six days.

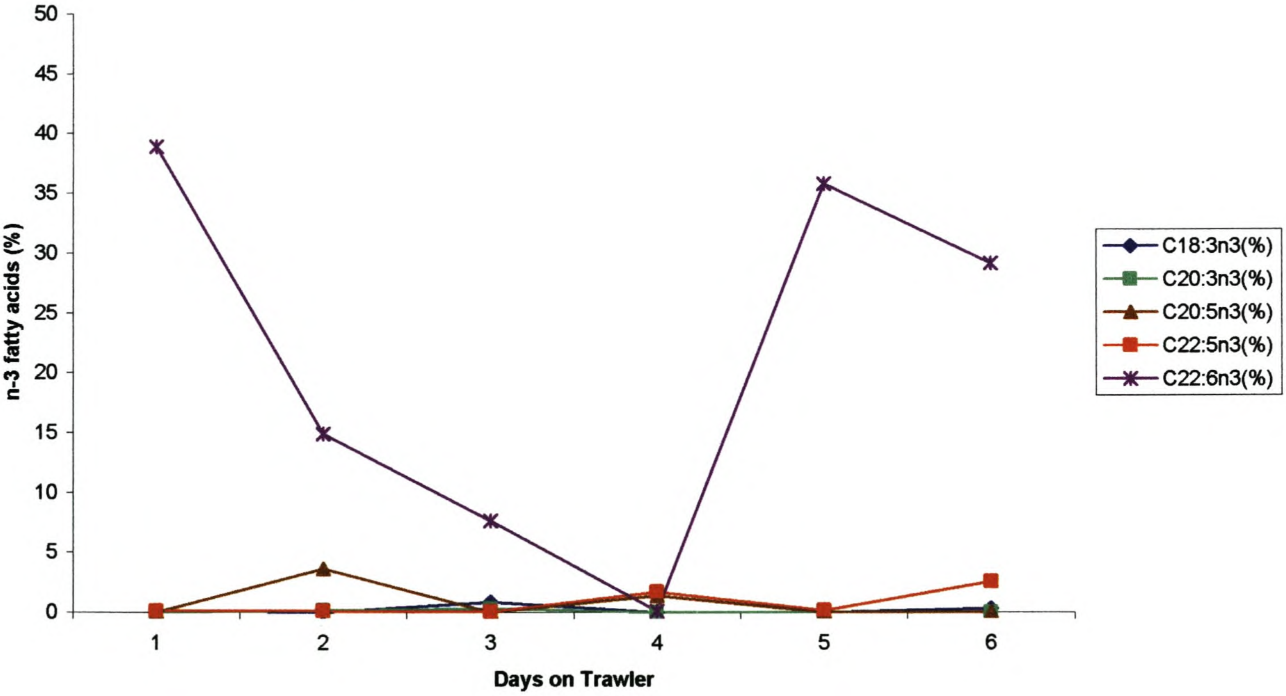

Figure 28. Change in percentage n-3 fatty acids of category 4 clean head sections over a period of six days.

Figures 29-32 show the n-6 fatty acid content (linolenic (C18:2n6), γ-linolenic (C18:3n6), eicosadienoic (C20:2n6), dihomo-γ-linolenic (C20:3n6), arachidonic (C20:4n6), docosadienoic (C22:2n6) & docosateraenoic (C22:4n6) acid) over a six day period for all categories of the clean head. The most prominent fatty acid in the clean head seems to be arachidonic acid. The remaining fatty acids were all present in smaller amounts. Figures 33-36 show a similar n-3 fatty acid profile as for the clean head. Figures 37-40 show that linolenic acid was the most prominent and least stable n-6 fatty acid present in the neck flesh followed by arachidonic acid.

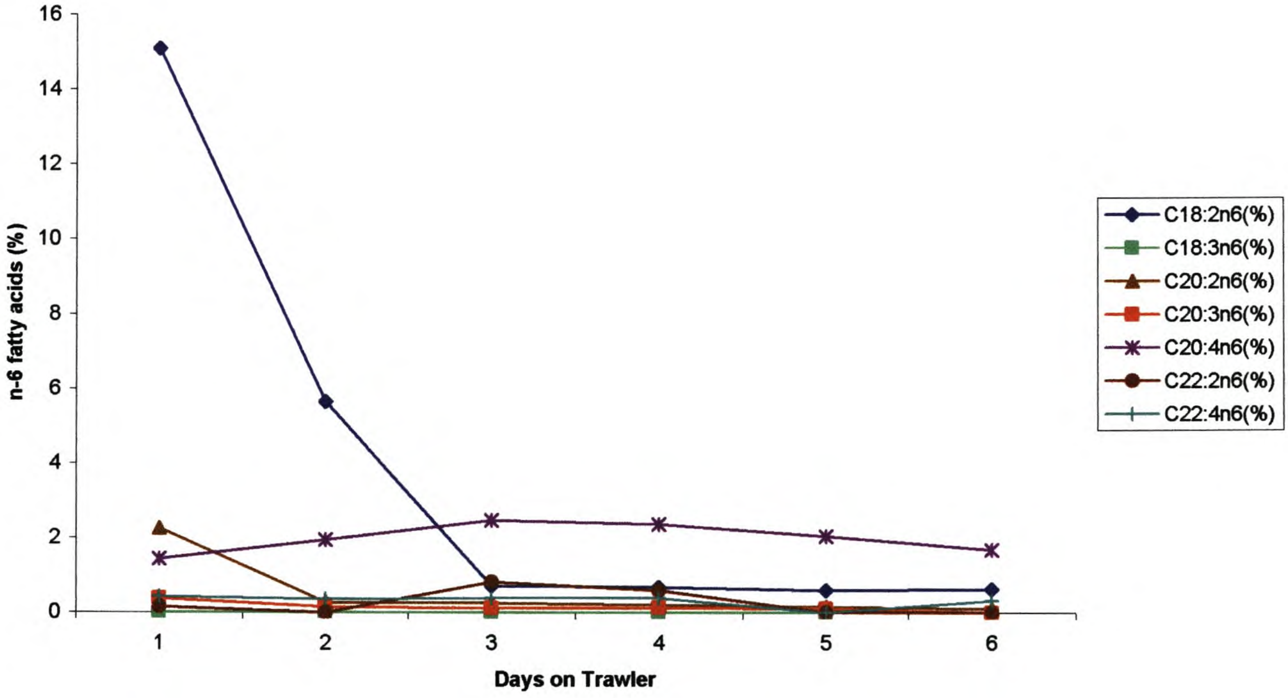

Figure 29. Change in percentage n-6 fatty acids of category 1 clean head sections over a period of six days.

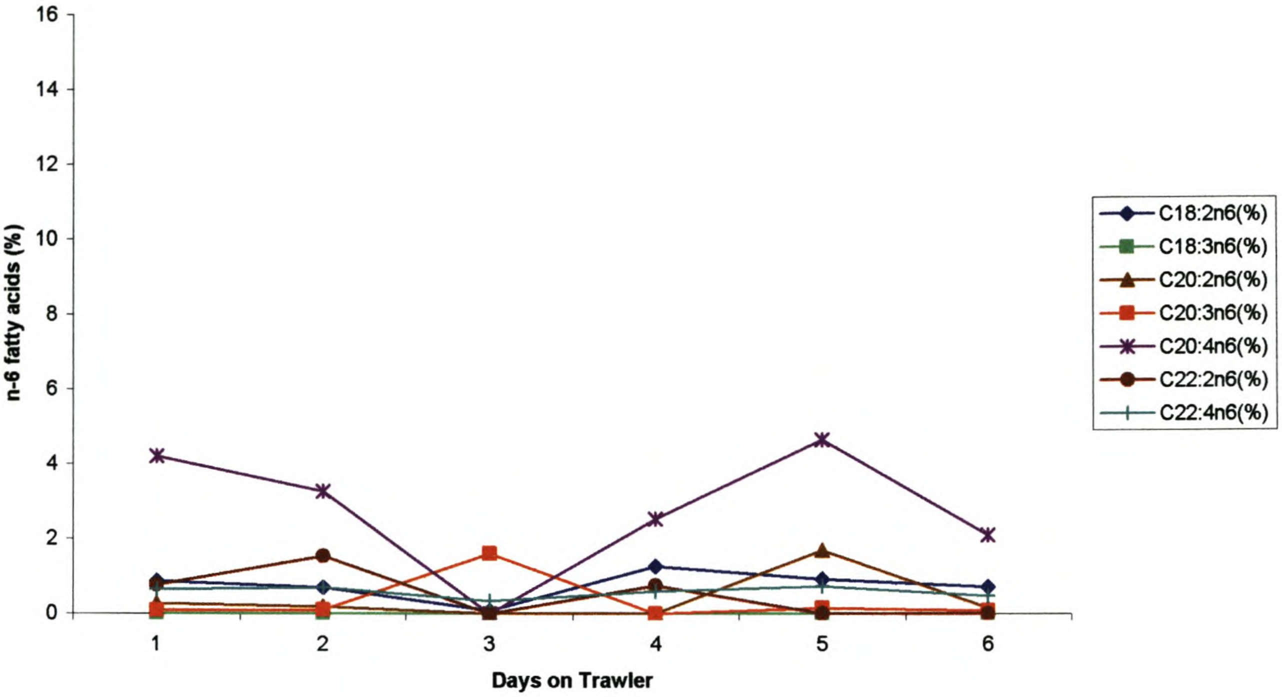

Figure 30. Change in percentage n-6 fatty acids of category 2 clean head sections over a period of six days.

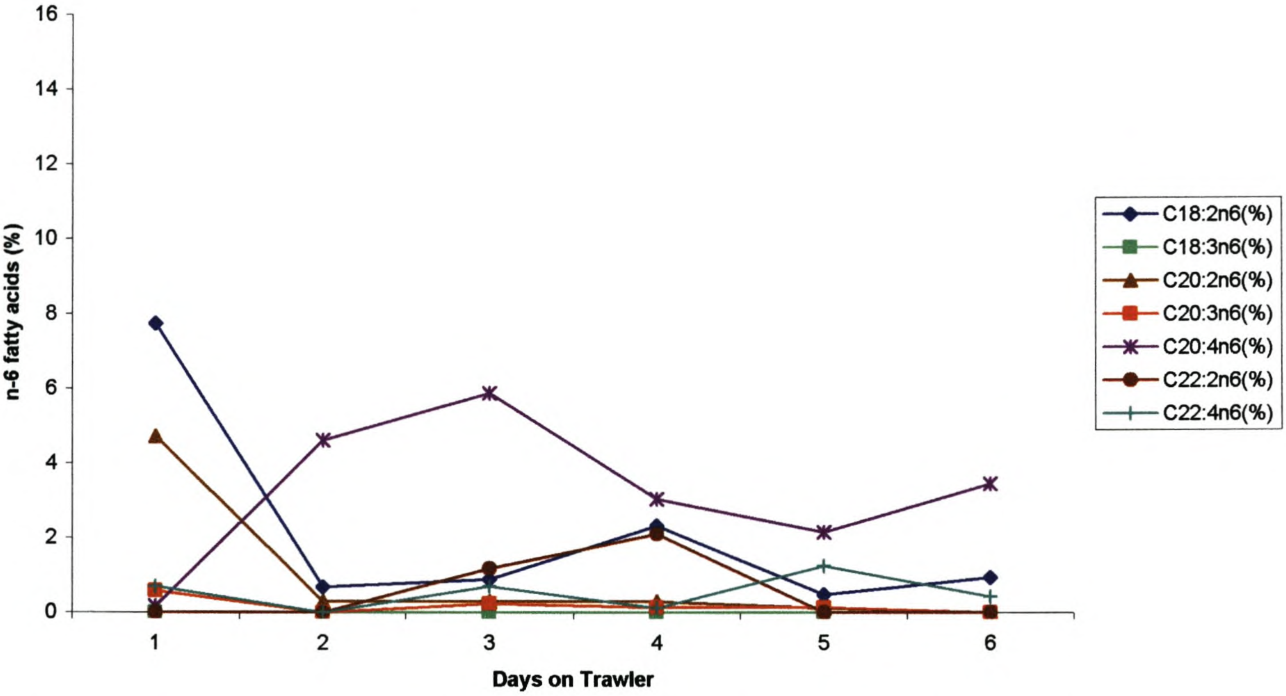

Figure 31. Change in percentage n-6 fatty acids of category 3 clean head sections over a period of six days.

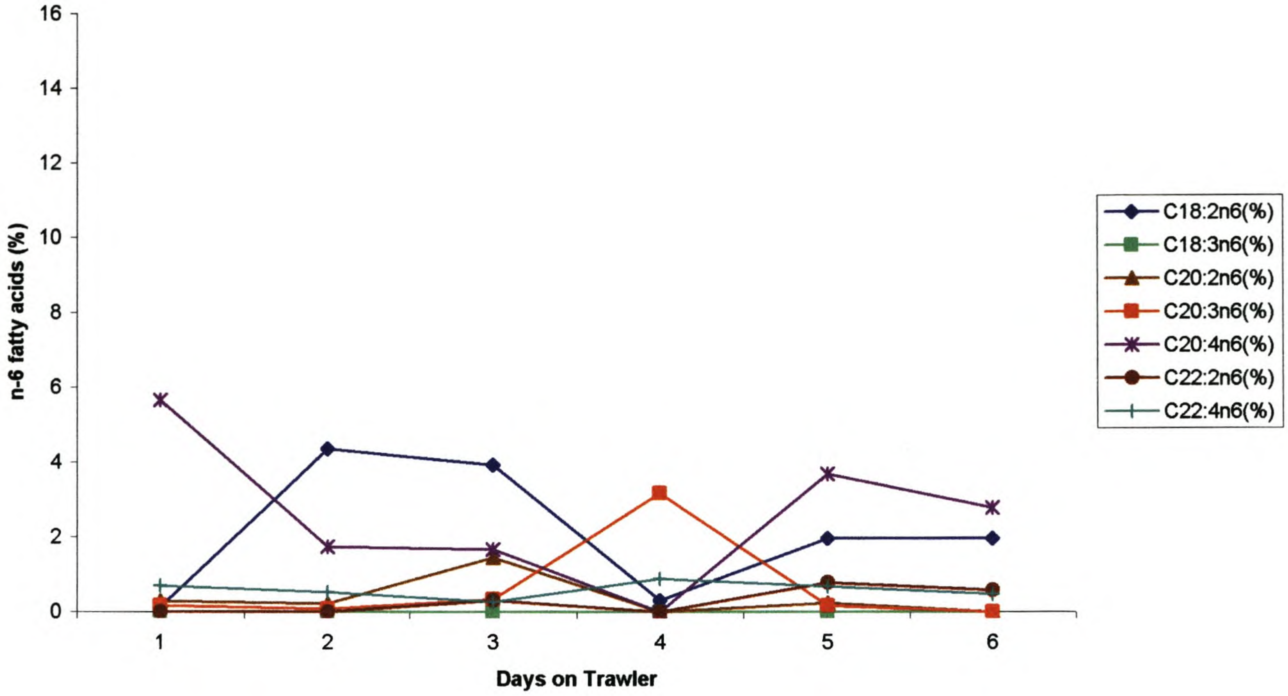

Figure 32. Change in percentage n-6 fatty acids of category 4 clean head sections over a period of six days.

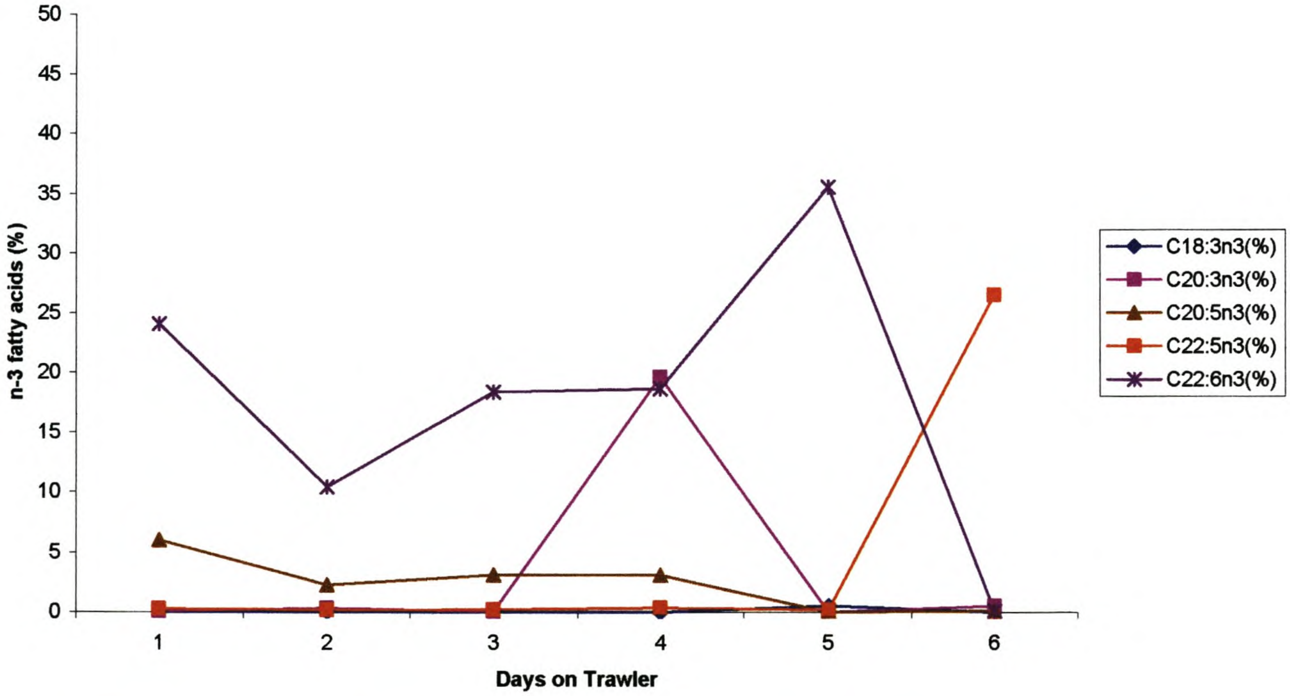

Figure 33. Change in percentage n-3 fatty acids of category 1 neck flesh sections over a period of six days.

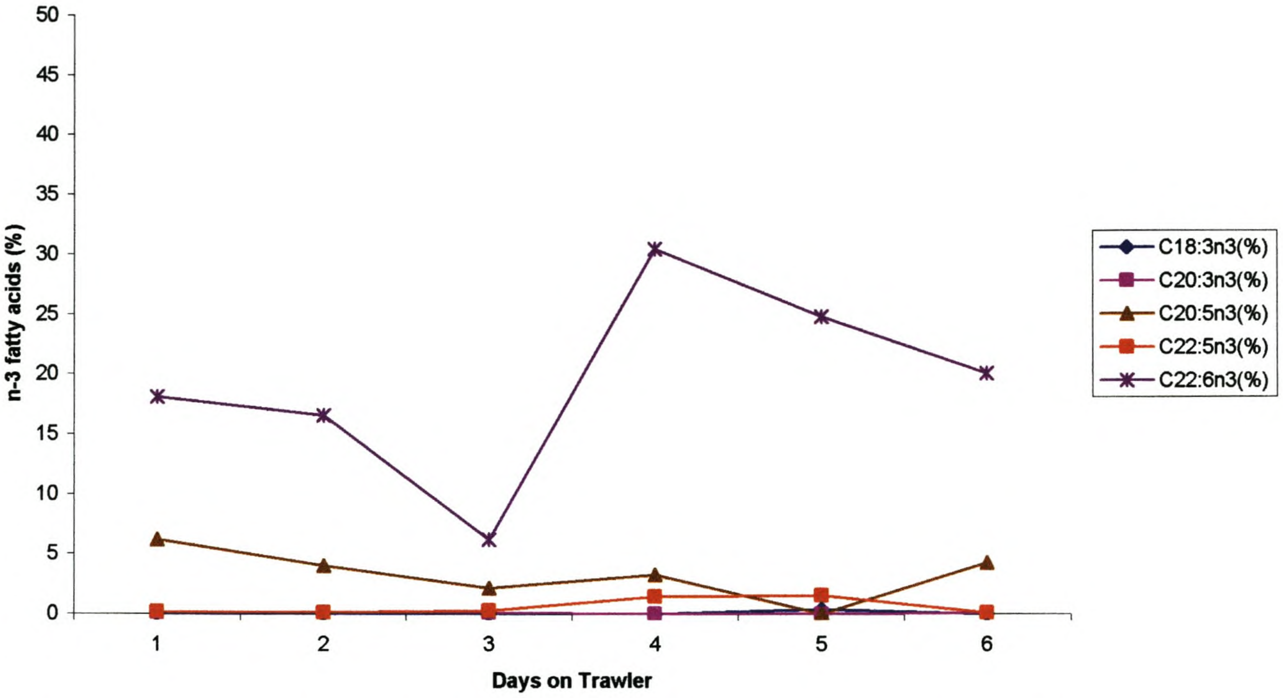

Figure 34. Change in percentage n-3 fatty acids of category 2 neck flesh sections over a period of six days.

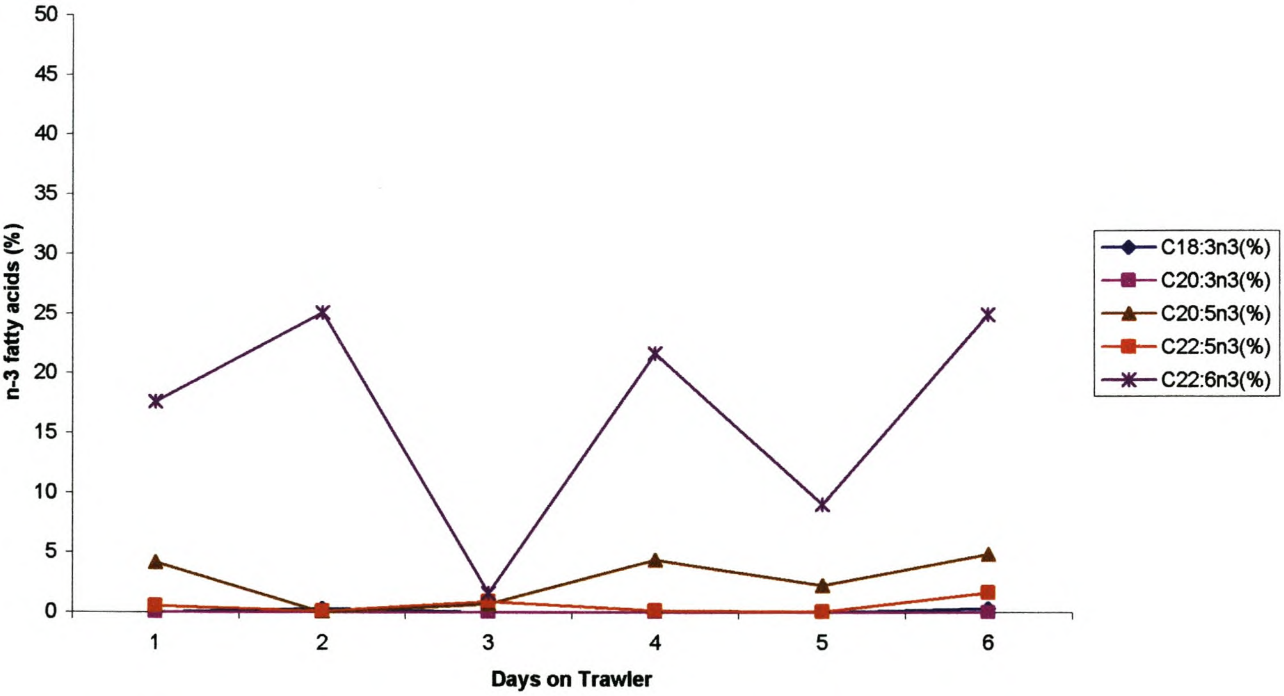

Figure 35. Change in percentage n-3 fatty acids of category 3 neck flesh sections over a period of six days.

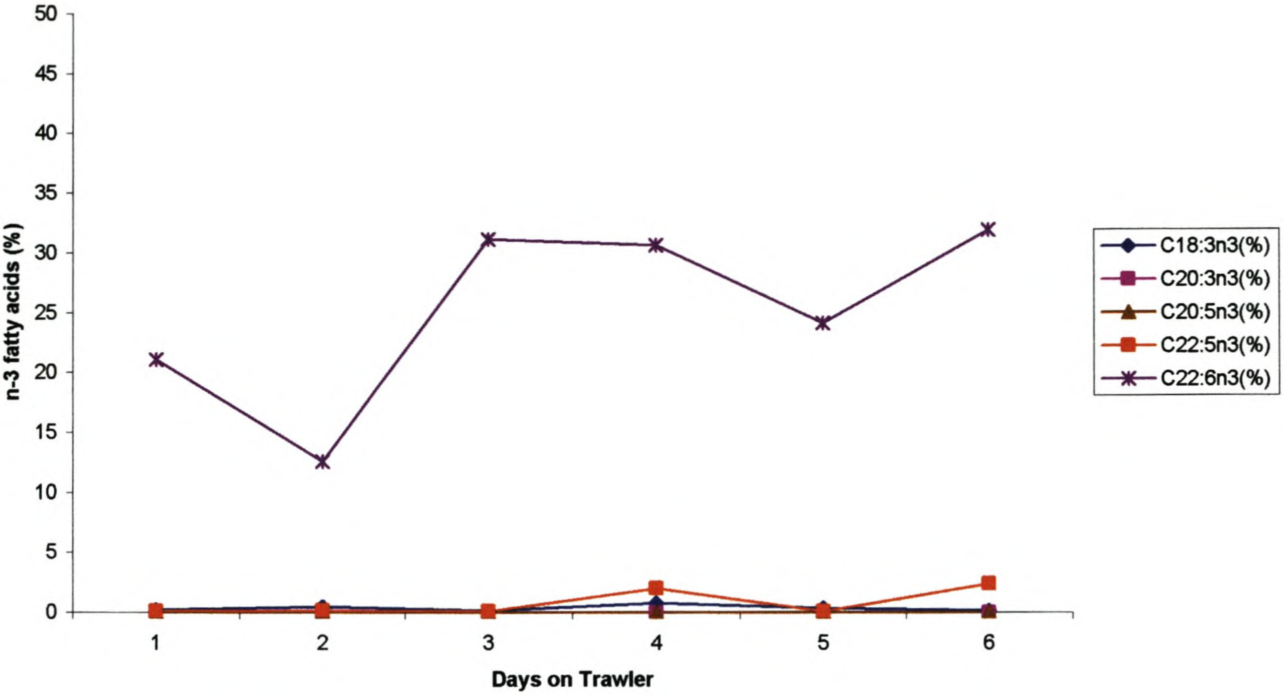

Figure 36. Change in percentage n-3 fatty acids of category 4 neck flesh sections over a period of six days.

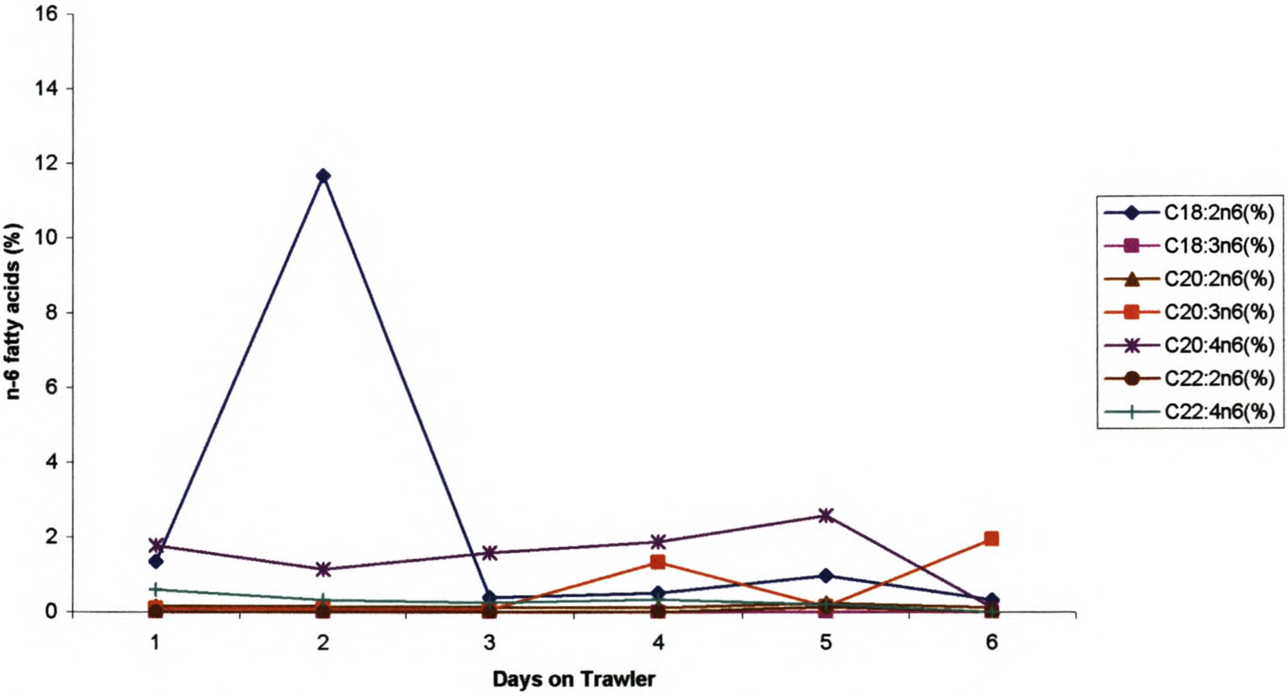

Figure 37. Change in percentage n-6 fatty acids of category 1 neck flesh sections over a period of six days.

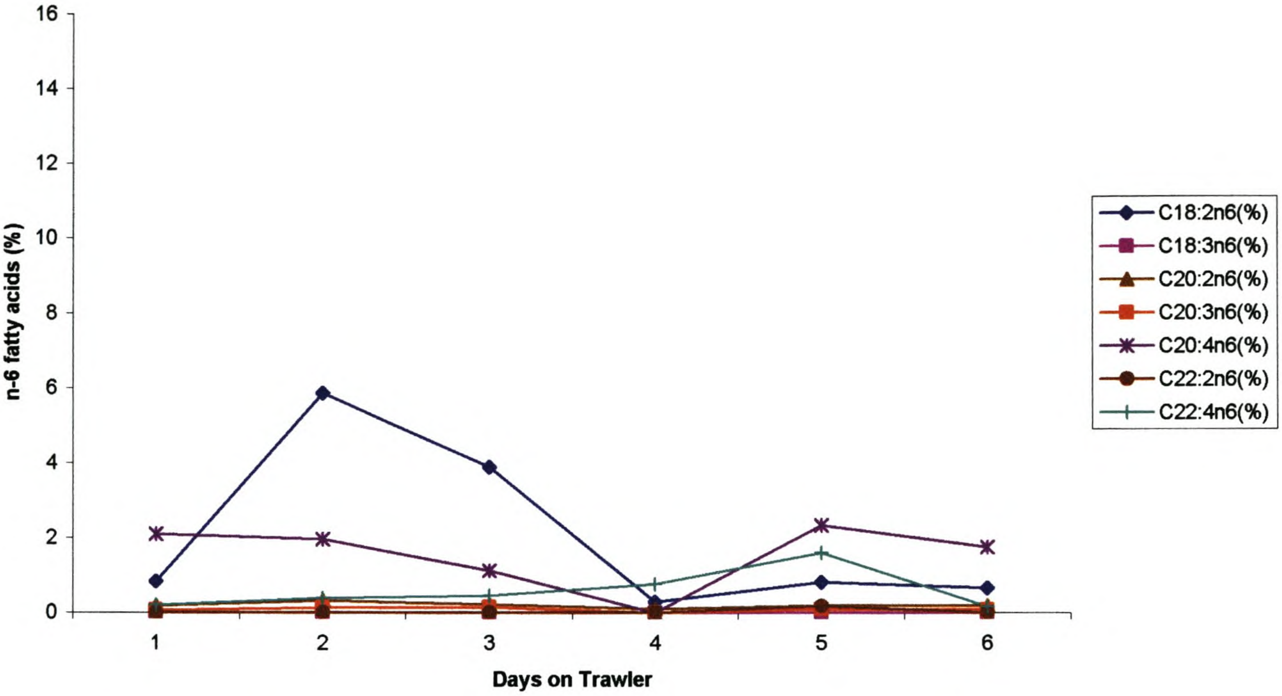

Figure 38. Change in percentage n-6 fatty acids of category 2 neck flesh sections over a period of six days.

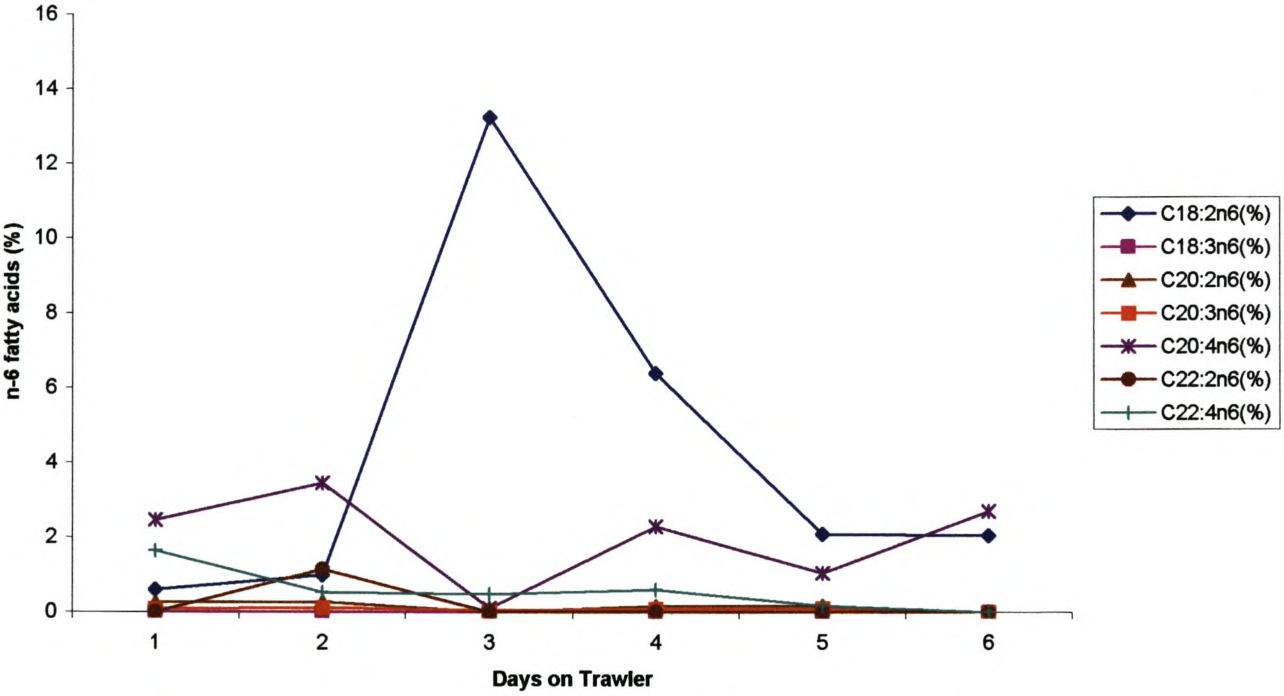

Figure 39. Change in percentage n-6 fatty acids of category 3 neck flesh sections over a period of six days.

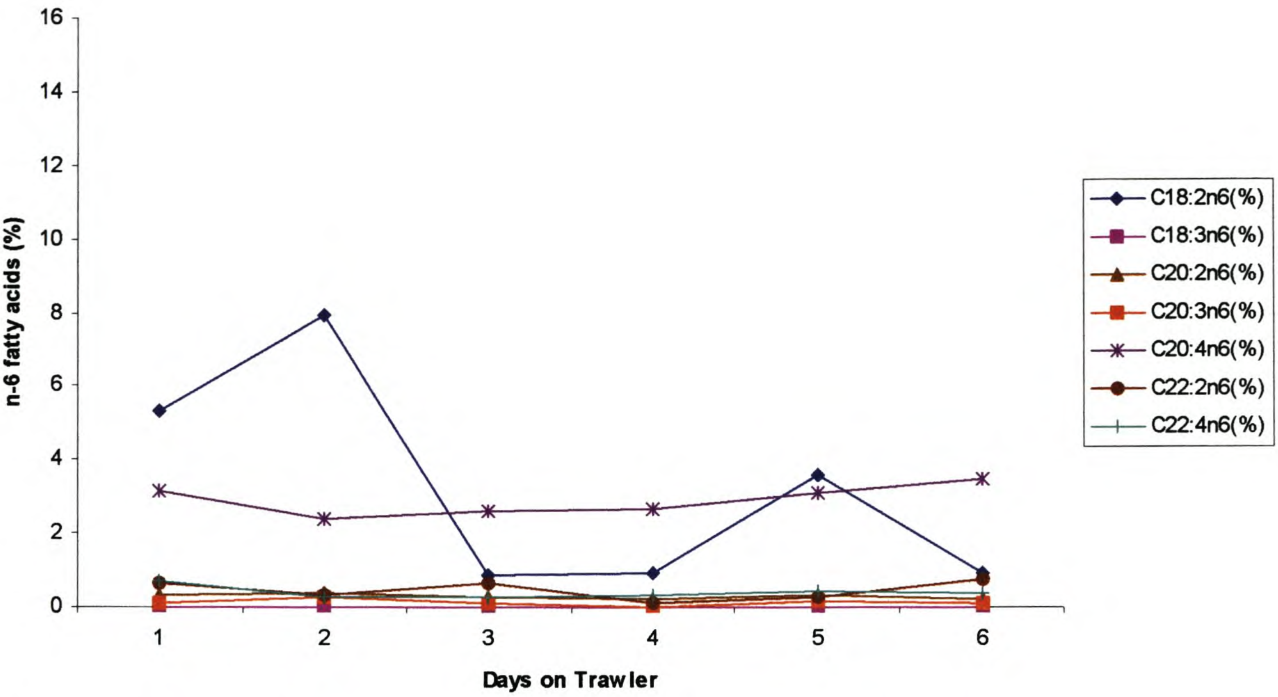

Figure 40. Change in percentage n-6 fatty acids of category 4 neck flesh sections over a period of six days.

Figures 41-44 show the change in saturated (SFA), mono unsaturated (MUFA), n-3 and -6 fatty acids for the clean head for all categories. The respective results for the neck flesh are in Figures 45-48. For both the clean head and neck flesh there seems to be an inverse relationship between SFA and MUFA (r= -0.40) as well as between n-3 and -6 (r= -7.50) fatty acids. Besides the good Pearson's correlation coefficients calculated this can also be substantiated by similar results shown in Figures 49 and 50 for the pooled results obtained for the clean head and neck flesh, respectively.

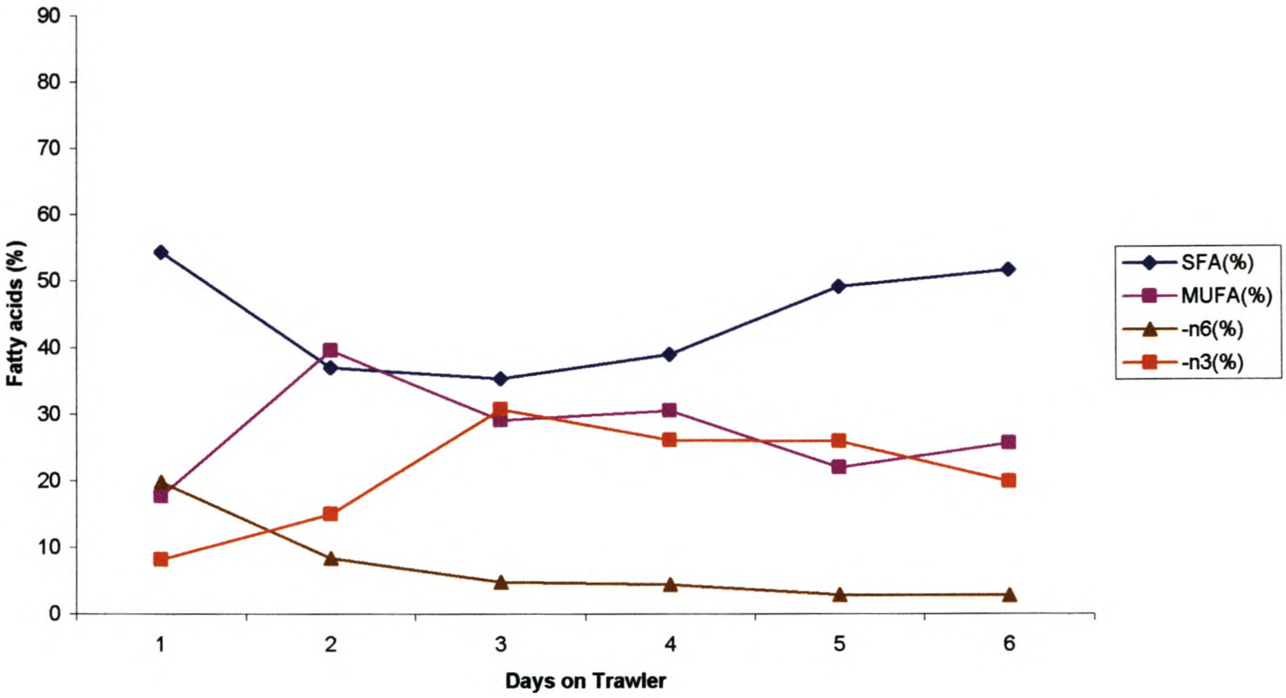

Figure 41. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 1 clean head sections over a six day period.

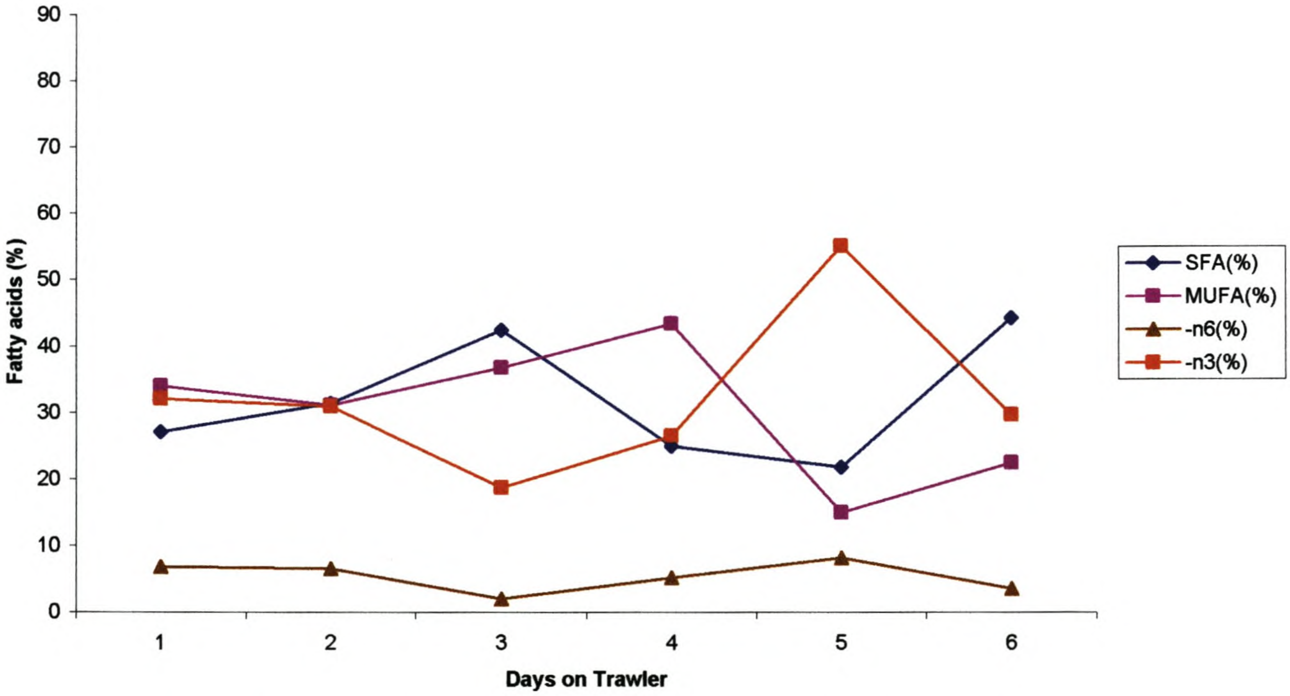

Figure 42. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 2 clean head sections over a six day period.

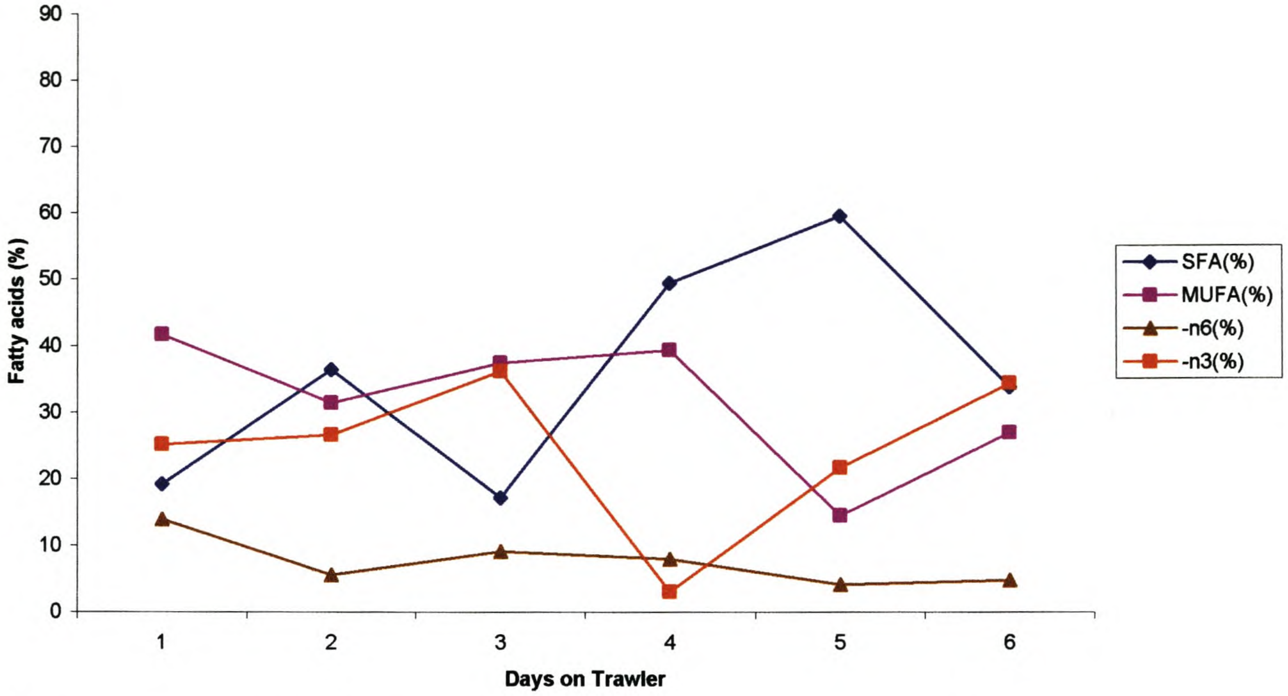

Figure 43. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 3 clean head sections over a six day period.

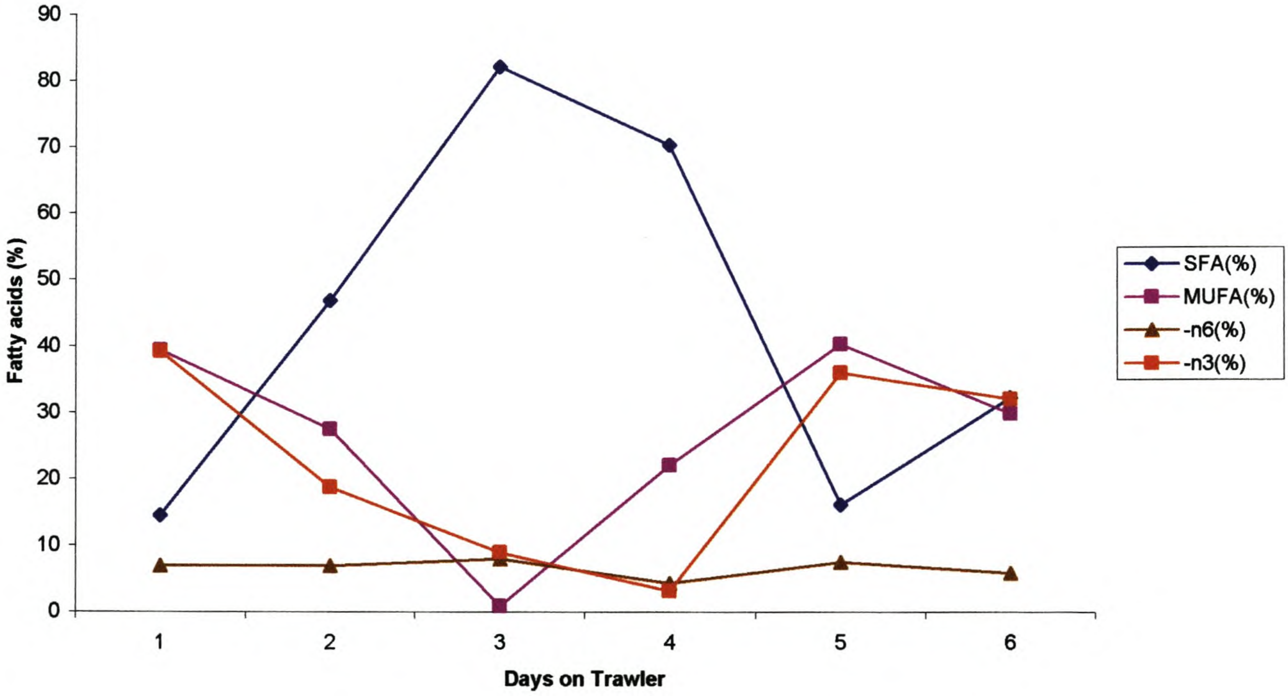

Figure 44. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 4 clean head sections over a six day period.

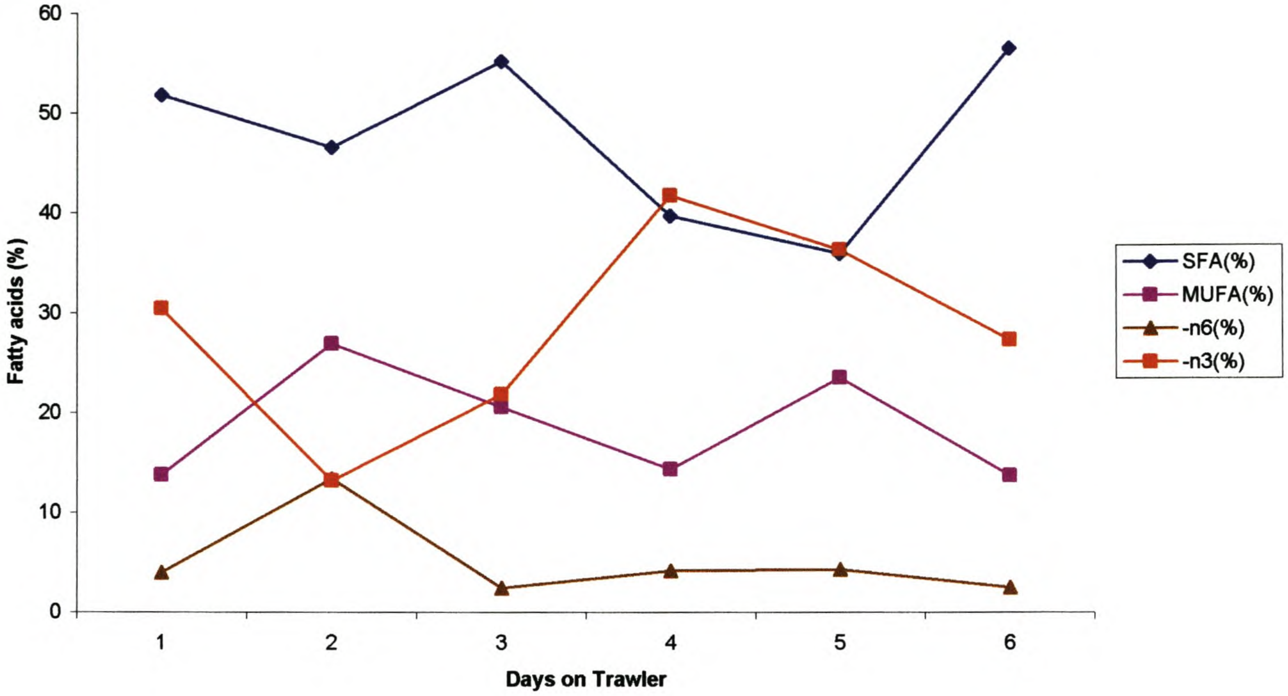

Figure 45. Change in percentage SFA, MUFA, n-3 and -6 fatty acids present in category 1 neck flesh sections over six days.

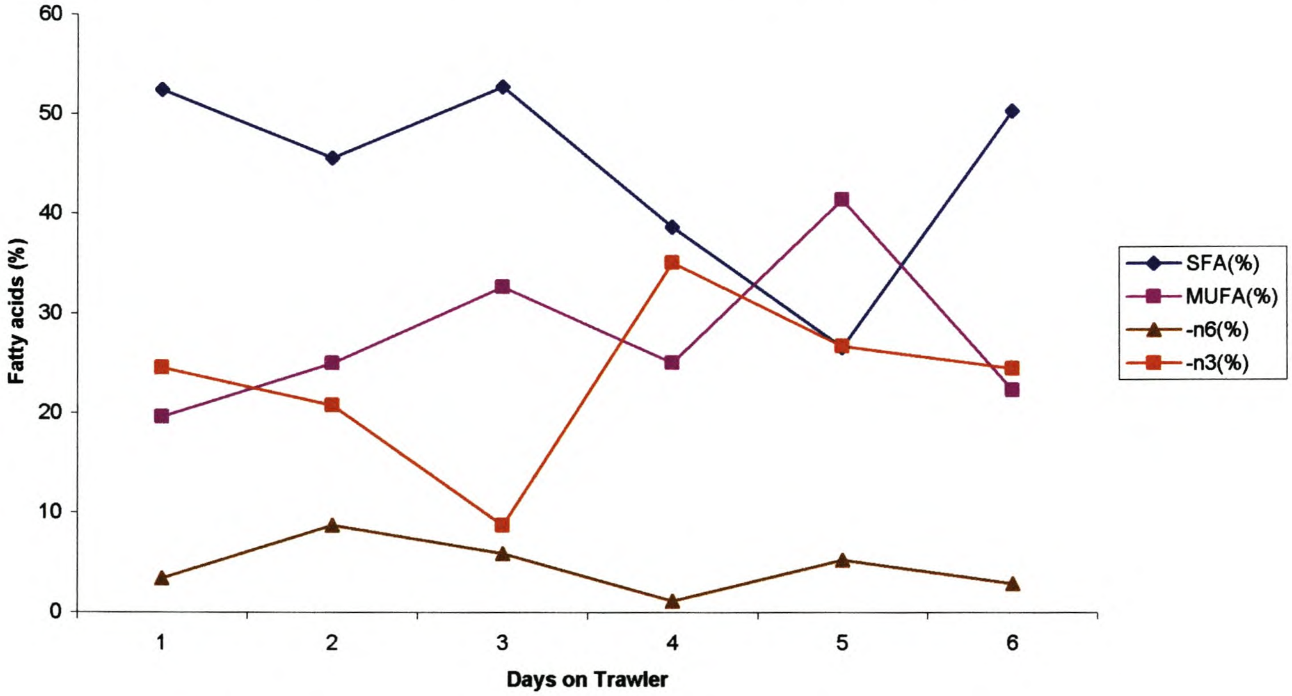

Figure 46. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 2neck flesh sections over six days.

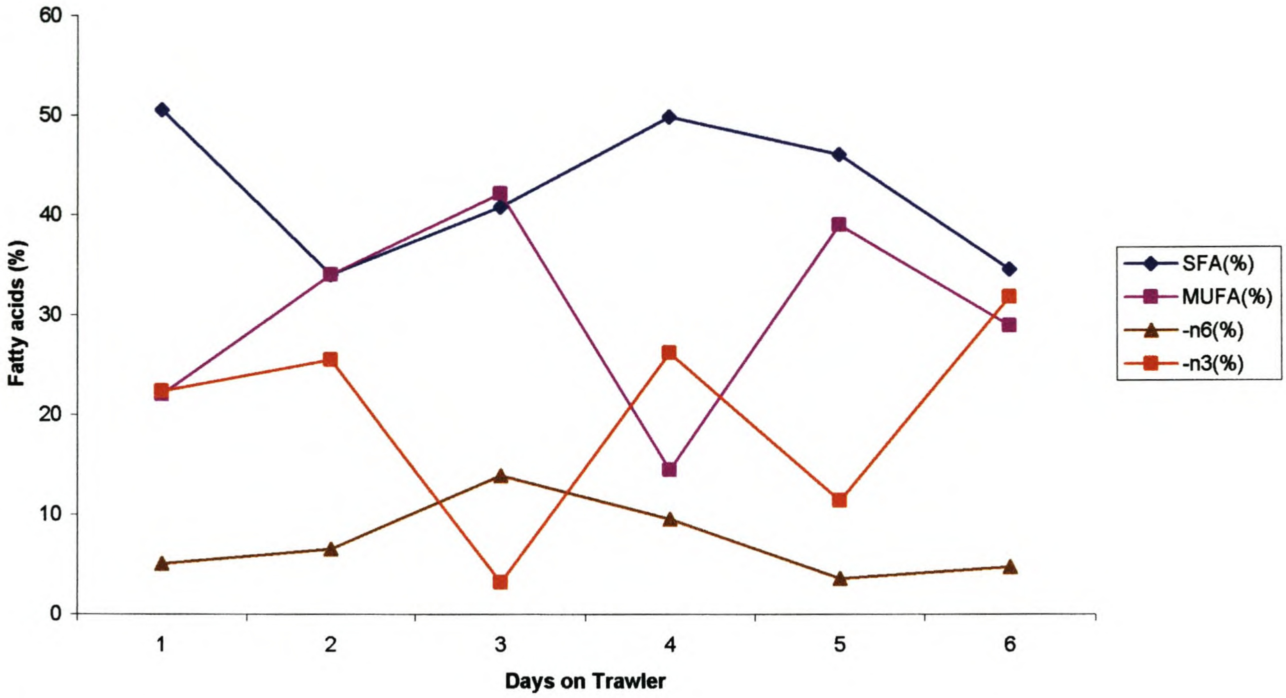

Figure 47. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 3 neck flesh sections over six days.

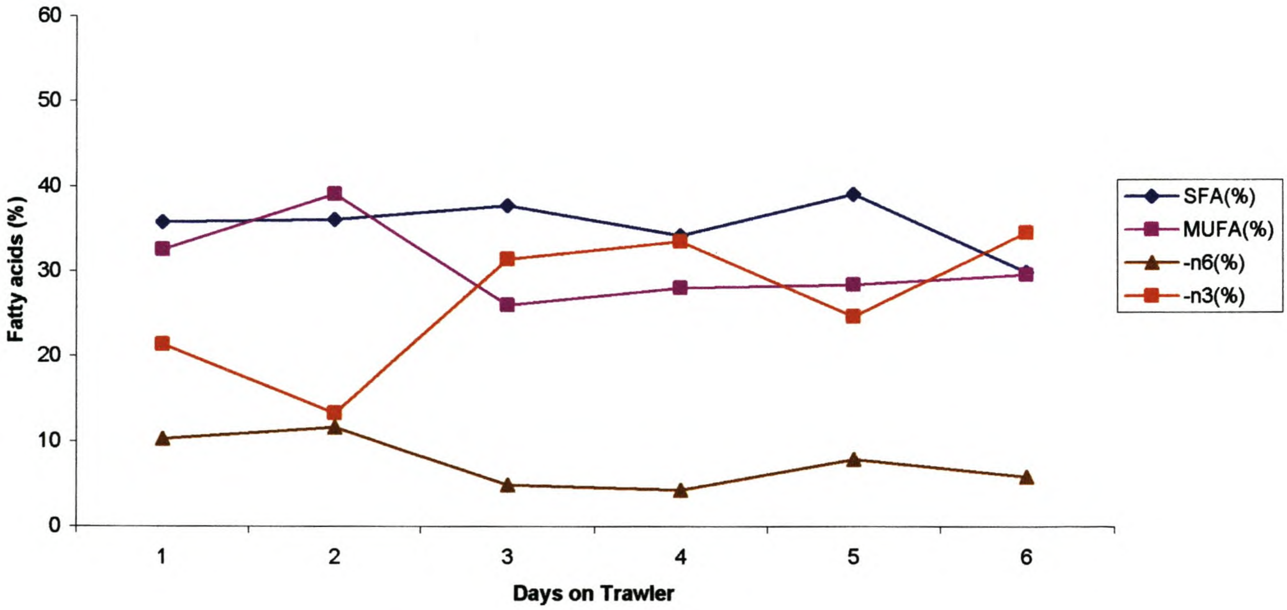

Figure 48. Change in percentage SFA, MUFA, n-3 and -6 fatty acids in category 4 neck flesh sections over six days.

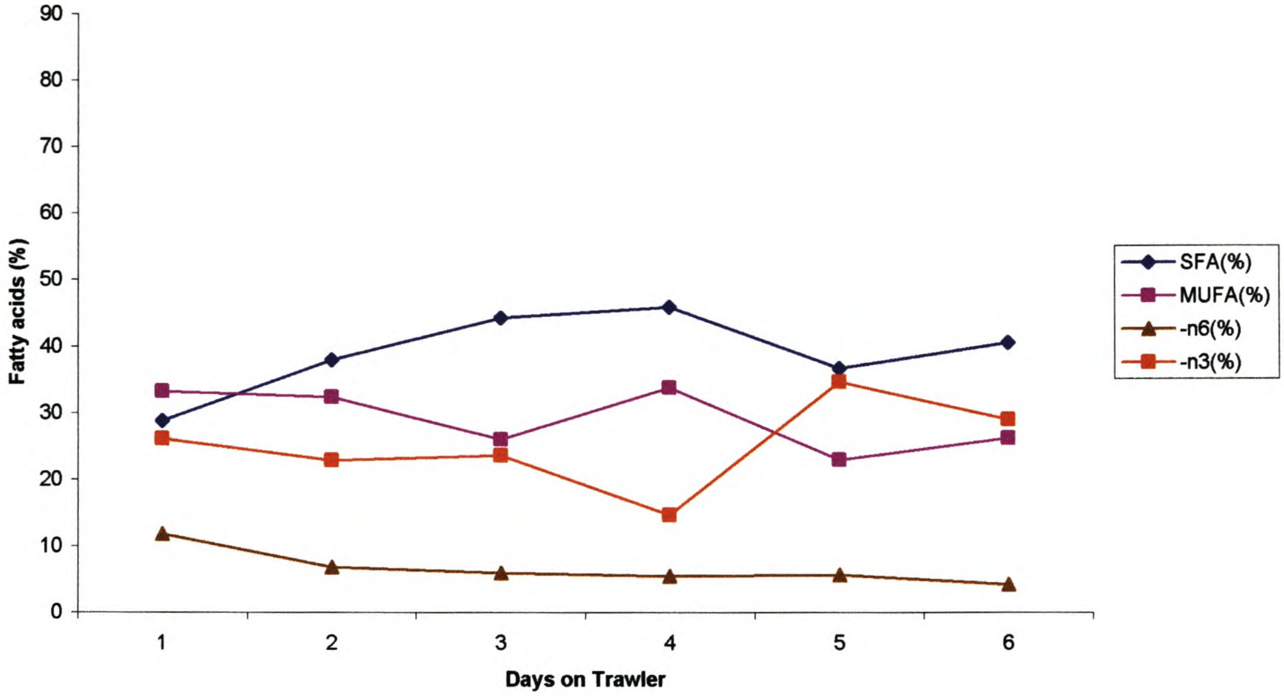

Figure 49. Change in mean percentage SFA, MUFA, n-3 and -6 fatty acids of categories 1-4 of the clean head section over a six day period.

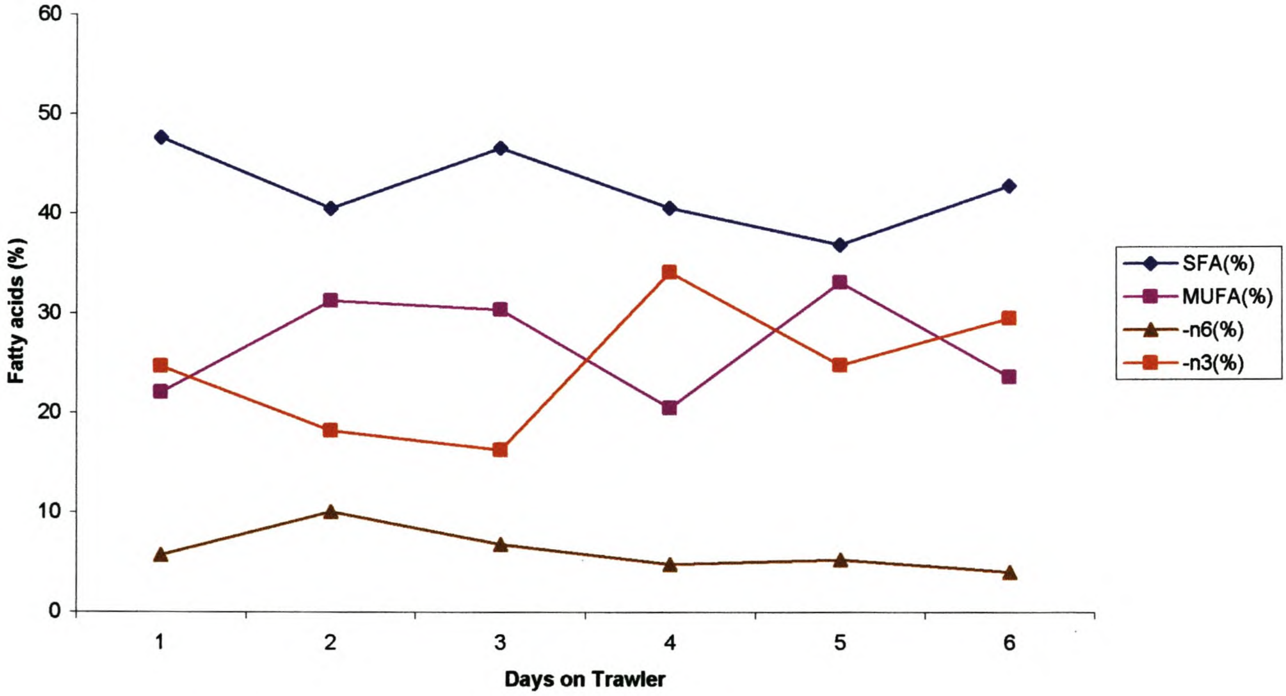

Figure 50. Change in mean percentage SFA, MUFA, n-3 and -6 fatty acids of categories 1-4 of the neck flesh section over a six day period.

Conclusion

The jaw would be a very good potential source of Ca. Even though it is not possible to chew and digest raw fish bone, however, it is technically possible to process some fish with bone by careful prior homogenisation. Differences in chemical analysis between different sections and categories could be attributed to several factors namely, different species; different sections of the fish; size of fish; state of sexual maturation; and seasonal differences. Random selection of samples may have reduced any possible bias, however, this led to certain category classes (categories 3 and 4) being poorly sampled. Where the hake head sections, within a respective category, during the first boat trip differed significantly ($p<0.05$) from its respective sections per category during the third boat trip, this could be explained by both the fact that there were differences in the sample set sizes within categories across each boat trip and due to the third boat trip being executed during the Cape hake main spawning period. Significant differences ($p<0.05$) between specific sections within a respective category, sampled during the second and third boat trips' could probably be explained by the difference in sample sizes. It can be concluded that the moisture content can be considered a key component when determining the chemical composition of any hake head section since it affects all the other chemical constituents, either inversely or vice versa.

The results of chemical, nutritional or technological measurements on musculature are likely to vary according to the section analysed. Both the jaw and tongue cartilage were found to be ideal sources of P, K, Ca and Na. No major differences could be detected between the three main groups (PUFA, MUFA and SFA) of fatty acids. The results would have been more easily interpreted if the fatty acids were analysed for each individual hake head section.

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Chapter 7

General discussion and conclusion

Cape hake (*Merluccius capensis* and *M. paradoxus*) is commercially the most important trawl-caught fish off the South African coastline (Fishing Industry Handbook, 2002). Besides its commercial importance it is also regarded as one of the single most important consumable natural resources, either in the raw or frozen form, due to its high protein content and because it is rich in long-chain highly unsaturated fatty acids (Méndez *et al.*, 1996; Vareltzis *et al.*, 1997). Currently the fish processing industry is based on intensive processing, resulting in large amounts of waste production (skin and connective tissue) that are normally discarded at sea (Borderías & Montero, 1991; Borderías *et al.*, 1999).

Most of South Africa's commercially trawled demersal fish has already been partially cleaned (i.e. headed and gutted) before landing (Chalmers, 1976). Non-marketable bycatch (non-target species) and hake-waste (hake heads) are normally disposed of as discards (that portion of the catch returned to the sea (or otherwise thrown away) as a result of economic or legal considerations), resulting in a waste of a potential protein source (Clucas, 1996).

This study was aimed at fulfilling several objectives, i.e. observing the current large-scale commercial hake harvesting procedure; construct prediction models for several morphological parameters (whole hake mass, headed & gutted hake mass, hake head length, hake head breadth and hake head height) of Cape hake (*Merluccius* ssp.) using whole hake length as the independent variable; and determine the chemical composition (moisture, protein, fat, ash, macro and trace elements) of several hake head sections (clean head, neck flesh, tongue, tongue cartilage, jaw, gills, heart, intestines, gut, kidney, kidney & kidney bone and gut & gall); as well as the effect that storage has on the fatty acid profile of both the clean head and neck flesh sections. The results obtained would supply data required for the techno-economic investigation in the use of hake heads.

It was observed that several steps could be instituted to increase yield and ensure the quality of the hake harvested. Firstly, the net openings, which are created by the float balls, could be increased from a two or three meter diameter opening to a five meter opening thereby increasing the tonnage hake hauled per drag, and shortening the period the trawl boat is out at sea. This would result in a more superior product regarding freshness and shorten the time it takes to get the hake onto local and foreign markets. The stock-up pond could be equipped with more than one opening onto the conveyor belt since this leads to congestion, resulting in workers mishandling the fish to ensure a constant flow of fish from the stock-up pond to the conveyor belt. This results in the damaging and bruising of the catch, which inevitably decreases its value. The existing deheading machine (piano blade) could be equipped to dehead small, medium and large hake since the current machine is built for the sole purpose of deheading big hake and could possibly damage smaller hake during the deheading process. The point of severing the hake head from the rest of the body could be executed closer to the gills since there is still quite a considerable amount of hake muscle attached to the head after deheading.

The factories currently use visual judgement to grade all landed hake and a more objective and accurate method would be advantageous. To maximise the use of the hake-waste the discarded hake head and the roe section of the hake gut should be retained, depending on the availability of space in the cold room, since the hake head can be regarded as a possible protein source whereas the roe does have an on land value. Another suggestion would be to also retain bycatch, which could be processed on a single line with no deheading taking place, only gutting. It is also suggested that each drag be restricted to the allocated time of *ca.* 2 hours, which would increase the quality of the hake. This study also confirms that dragging should take place during the optimum time of the day (i.e. 07:00-17:00) thereby limiting the number of juvenile to medium size hake caught, and ensuring a favourable harvest.

Prediction models can be regarded as a beneficial asset within the fishing industry as it can be used to make informed decisions to decrease the risk factor during decision-making. However, one should bear in mind that calculated conversion factors or prediction models for a given species are subject to variation between different areas due to variations in biological factors (i.e. availability of food and maturity state of fish) and cleaning processes (Chalmers, 1976). Prediction models were thus constructed for each of the morphological parameters (whole hake length, whole hake mass, H & G hake mass, hake head mass, length, breadth and height).

For each of the six prediction models (whole hake mass, H & G hake mass, hake head mass, hake head length, hake head breadth and hake head height) constructed there was an increase in the variance of the data points of categories 3 (64-80 cm) and 4 (>80 cm) as opposed to categories 1 (30-46 cm) and 2 (47-63 cm). This could be attributed to a smaller sample set for both categories 3 and 4 or due to an expected increase in the variance when investigating larger biological samples. There was also a clustering of data in the three areas for each prediction model namely; within category 1 and across categories 2 and 3 and 3 and 4. This emphasises the latitudinal stratification of the Cape hake population by age, hence their stratification by size. The prediction models constructed for both boat trips 2 and 3 differed significantly ($p<0.01$) from that of boat trip 1, with the exception of the hake head length (cm) prediction model. This may be attributed to the increased sample sizes sampled during boat trips 2 and 3 as opposed to boat trip 1 or to the fact that boat trips 2 and 3 were sampled while the Cape hake were well into their main spawning season while those sampled during boat trip 1 was during the secondary spawning season or due to a combination of the aforementioned reasons. This variation between the prediction models of boat trips 2 and 3 and those constructed for boat trip 1 can, however, not be attributed to the diurnal feeding habit of Cape hake since all samples investigated were taken during daytime catches. The constructed prediction models, for each of the three respective boat trips, have good predictive abilities indicated by the low Mean Square Error (MSE) values for the test sets and high Pearson's correlation coefficient (r) values. These prediction models constructed can be used in the fishing industry with confidence for Cape hake within the time frame each respective boat trip was carried out.

Chemical status of fish muscle may vary due to their state of sexual maturation, seasonal change or size of the fish. Differences in chemical analysis between different sections and categories could also be attributed to different species and different sections of the fish. It can therefore be concluded that the biological condition of the hake, which is related to its reproductive cycle influences its biochemical and functional properties. No major differences could, however, be detected between the three main groups (PUFA, MUFA and SFA) of fatty acids. The results would have been more easily interpreted if the fatty acids were measured for each individual hake head section. The protein and fat content was inversely proportional to the moisture content with the exception of the ash. It could therefore be deduced that the moisture content analysis may be considered a key chemical analysis since moisture content is the only chemical constituent, which affects all the remaining constituents, inversely or vice versa when considering large-scale commercial production. As the fat content of the intestines was quite high it would be advisable to remove these sections before commercial processing of a food or feed as the susceptibility of the fats to oxidation would decrease the shelf life of the end product dramatically.

The neck flesh could be regarded as the most important concerning chemical composition whereas the jaw could be seen as the most important when one considers mineral content. This therefore means that the jaw section, once appropriately processed, is a potential Ca, Na and Fe source for supplementing diets of people suffering from a Ca, Na or Fe deficient diet. With regard to chemical status the neck flesh section is seen as a good potential source of both protein and fat, which could be attributed to the fact that hake muscle constitutes a major portion of this section. This section could thus be used to supplement the protein and fat of an existing food product, which is protein and fat deficient for people suffering from a protein and fat deficient diet. Similarly, a market could be created for the production of an economical food product with the neck flesh section being the main ingredient. This food product, aided either directly or through government feeding programmes, would then cater for the needs of the bulk of South Africa's population suffering from a protein and fat deficient diet. This substantiates the fact that fish-waste could be a good source of nutrients, but in order to retain this value careful control of the degree of proteolysis and lipid oxidation is required during processing (Dapkevičius *et al.*, 1998). In order to construct the ideal processing procedure and to evaluate the respective hake head sections as a nutrition product their chemical composition (moisture, protein, fat, ash, macro and trace elements) needed to be determined.

Once this has been accomplished, fishing vessels may be persuaded to retain their fish-waste for further processing due to the value of the prepared food products and thereby maintain profitability while abiding to governmental law. Besides the current discarding of fish heads at sea there is also a growing demand to utilise the large volumes of fish-waste produced on land in aquaculture practices, with the sole purpose of supplying world demand due to dwindling ocean stocks.

Since the South African marine environment is over-exploited and with this degree of degradation increasing in the foreseeable future appropriate policies and more strict legislation should be drafted to try and avoid any such occurrences. Major emphasis, should be placed on improving existing resources, infrastructure and corporate incentives. In conclusion non-government scientists should have more input in the decision-making process concerning matters affecting South Africa's marine biodiversity in order for future key policy and legislation drafts to be effective. Improvement of current fish preservation techniques and the informed chemical composition of currently discarded material will result in informed decisions of future matters concerning its disposal.

Government incentives, based on a fixed price per kilogram for both bycatch and hake-waste landed, should be created for the landing and further processing of both bycatch and hake-waste harvested. Secondary processing of the bycatch and hake-waste landed could either, be carried out by the existing commercial fishing industry or by creating an industry specialising in bycatch and hake-waste processing. It will be important to keep the price fixed for all species since species based incentives would create bias within the fishing industry towards landing specific species. A year round market should also be created for these diverse species of bycatch and hake-waste by creating an attractive consumer market to ensure profitability and economic feasibility. Government should also invest more money into marine research, particularly bycatch and hake-waste, by both independent research companies and tertiary institutions to determine the impact the current hake harvesting procedure has on the hake population itself as well as the diverse bycatch species also affected during this harvesting procedure. Once proper infrastructure is in place and the respective markets have been well established then government or even corporate business need only to maintain the running costs of employing inspectors who would obtain valuable information about the bycatch and hake-waste landed. This in effect would create a double effect since valuable scientific information would be obtained about South Africa's demersal stock as well as the ripple effect of job creation. This would then enable the fishing industry to increase their harvesting efficiency as well as allowing them to make informed decisions concerning the harvesting of a specific fish species.

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Appendix 1:

Table 1. Length, breadth, height and mass of hake head samples sampled during drag (*ca*. 09:00 - 11:00).

Hake head #	Length (cm)	Breadth (cm)	Height (cm)	Mass (kg)
1	22.442	11.174	11.160	1.240*
2	20.601	9.770	9.409	0.880*
3	21.936	11.366	10.976	1.380*
4	20.418	10.588	10.419	0.960*
5	22.220	10.653	12.053	1.280*
6	19.969	9.809	11.389	1.020*
7	19.837	7.748	11.733	0.780*
8	18.269	9.839	11.291	0.780*
9	18.565	9.410	9.998	0.760*
10	17.333	8.575	10.649	0.640*
11	19.367	8.168	12.544	0.780*
12	17.714	8.044	9.935	0.620*
13	17.243	9.673	10.542	0.720*
14	14.700	7.037	7.466	0.340*
15	12.641	5.938	6.677	0.220*
16	14.345	6.854	8.841	0.400*
17	13.484	7.641	9.059	0.420*
18	14.787	6.640	7.508	0.400*
19	14.132	7.649	8.126	0.400*
20	15.009	7.458	8.609	0.460*
21	18.521	9.133	11.320	0.900*
22	14.670	6.927	8.862	0.380
23	17.997	8.222	9.348	0.780
24	16.292	7.772	9.903	0.600
25	20.605	9.940	10.742	1.040
26	19.746	7.615	12.027	0.700
27	16.518	7.019	10.029	0.560
28	17.828	9.111	8.241	0.640
29	15.726	6.875	9.155	0.500
30	17.948	8.475	10.573	0.620
31	24.624	11.830	13.466	1.580
32	16.618	7.634	8.420	0.520
33	16.332	7.122	10.827	0.560
34	16.835	7.645	9.813	0.580

*A small amount of the hake head intestines removed.

Table 2. Length, breadth, height and mass of hake head samples sampled during drag (*ca.* 13:00 - 15:00).

Hake head #	Length (cm)	Breadth (cm)	Height (cm)	Mass (kg)
1	20.187	9.967	10.501	1.260
2	16.202	7.389	9.857	0.660
3	17.164	10.180	12.380	0.900
4	16.226	8.145	8.627	0.580
5	18.209	7.916	9.920	0.780
6	14.069	6.172	8.886	0.380
7	18.068	7.654	9.468	0.740
8	19.574	8.435	10.855	0.880
9	17.668	8.756	10.134	0.800
10	18.071	8.613	8.047	0.740
11	17.228	7.874	10.554	0.680
12	19.081	8.354	10.766	0.880
13	19.828	10.441	10.863	0.980
14	20.663	9.538	10.625	0.940
15	18.566	10.530	9.829	1.040
16	18.760	10.361	9.902	1.040
17	20.387	9.118	10.951	1.040
18	18.398	9.219	10.131	0.840
19	15.523	7.483	7.485	0.460
20	17.084	8.655	9.729	0.600
21	18.439	9.868	10.343	1.200
22	17.121	7.061	9.073	0.580
23	20.610	8.489	11.397	0.920
24	18.140	9.113	11.090	1.060
25	17.030	8.235	9.509	0.620
26	12.687	5.930	6.844	0.280
27	16.669	7.513	9.382	0.680
28	17.774	8.568	10.415	0.860
29	16.488	6.652	8.194	0.480
30	20.612	8.879	9.678	0.940
31	12.424	6.070	8.025	0.260
32	13.657	6.075	8.668	0.360
33	13.951	6.976	7.551	0.400
34	14.394	7.902	8.791	0.400

Table 3. Length, breadth, height and mass of hake head samples sampled during drag 3 (*ca.* 16:30 - 18:30).

Hake head #	Length (cm)	Breadth (cm)	Height (cm)	Mass (kg)
1	16.132	7.170	9.833	0.460
2	17.636	7.531	8.037	0.520
3	24.207	9.693	14.161	1.540
4	14.426	6.187	6.138	0.320
5	19.130	9.155	11.545	0.940
6	15.475	6.797	8.269	0.460
7	16.061	8.526	9.227	0.640
8	14.461	7.716	8.054	0.400
9	12.123	5.021	6.225	0.180
10	17.719	7.280	7.820	0.520
11	13.864	6.831	7.144	0.320
12	11.592	4.885	5.280	0.160
13	13.009	6.049	6.663	0.280
14	15.586	7.463	8.336	0.460
15	12.165	5.449	6.981	0.240
16	13.171	6.269	7.154	0.340
17	13.115	5.934	8.370	0.260
18	20.612	9.060	10.422	1.080
19	12.720	5.810	6.480	0.260
20	13.087	6.982	6.798	0.260
21	13.313	5.914	7.243	0.260
22	11.941	5.615	5.968	0.220
23	14.182	6.074	8.082	0.300
24	16.876	7.798	9.741	0.700
25	14.422	5.984	9.116	0.360
26	13.855	7.916	8.492	0.380
27	14.674	6.938	7.503	0.380
28	16.048	7.143	8.350	0.460
29	17.140	8.415	11.024	0.760
30	12.156	4.990	7.619	0.260
31	14.534	7.218	7.856	0.440
32	14.063	5.809	7.778	0.300
33	11.991	4.814	6.312	0.200
34	15.747	5.866	8.224	0.380

Table 4. Length, breadth, height and mass of drag 4 hake head samples sampled during drag 4 (*ca*. 19:50 - 21:50).

Hake head #	Length (cm)	Breadth (cm)	Height (cm)	Mass (kg)
1	13.655	5.753	8.154	0.300
2	11.956	5.541	8.540	0.240
3	11.933	5.816	7.526	0.220
4	13.175	6.717	7.409	0.320
5	13.065	5.812	7.701	0.300
6	13.963	5.364	7.157	0.280
7	12.625	6.774	7.213	0.280
8	18.419	8.117	11.039	0.780
9	14.166	7.514	7.059	0.320
10	18.195	8.351	10.839	0.780
11	16.150	7.155	8.546	0.500
12	20.607	10.626	10.746	1.160
13	14.750	7.414	8.539	0.440
14	15.367	7.141	8.679	0.400
15	12.869	6.331	7.414	0.300
16	12.044	6.717	7.489	0.220
17	12.542	4.719	7.682	0.240
18	12.208	5.016	7.069	0.220
19	12.756	6.273	6.178	0.260
20	12.610	5.915	7.300	0.260
21	11.637	5.414	6.345	0.160
22	13.015	6.085	7.191	0.320
23	13.417	6.552	6.785	0.320
24	14.774	6.349	8.182	0.400
25	12.137	5.883	6.012	0.240
26	13.226	6.098	7.339	0.340
27	14.563	5.307	7.914	0.360
28	10.828	5.147	6.071	0.180
29	12.412	5.451	7.031	0.220
30	12.927	5.042	7.218	0.240
31	12.173	5.855	6.728	0.240
32	11.785	5.846	6.000	0.240
33	12.210	5.276	5.920	0.220
34	13.725	6.558	6.753	0.320

Appendix 2:

Table 1. The average moisture, protein, fat and ash content (%) of the neck flesh, clean head and jaw sections of the first lot of samples.

Hake head section	Group number	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Neck flesh	1	81.4250	14.9094	0.6350	2.5741
Neck flesh	2	83.0950	14.5257	0.6179	2.2661
Neck flesh	3	81.8450	15.4538	0.5589	2.5938
Neck flesh	4	82.3550	14.9648	0.5262	2.5524
Clean head	1	85.6650	11.6693	0.4890	2.9778
Clean head	2	85.1800	12.0881	0.4700	3.2259
Clean head	3	86.1050	10.8898	0.4196	3.4235
Clean head	4	85.2600	12.1529	0.4723	3.3341
Jaw	1	76.3250	14.2710	0.4946	6.2816

Table 2. The average moisture, protein, fat and ash content (%) of the neck flesh, clean head and jaw sections of the second lot of samples.

Hake head section	Group number	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Neck flesh	1	78.9050	21.2032	1.0467	2.7580
Neck flesh	2	78.4500	19.8031	1.0845	2.9661
Neck flesh	3	77.5300	20.7538	1.0651	2.8214
Neck flesh	4	78.5000	19.4927	1.1810	2.8311
Clean head	1	84.0550	15.0164	0.9718	3.8824
Clean head	2	83.2650	15.0895	1.0520	3.6969
Clean head	3	82.0500	14.5413	1.1581	3.7623
Clean head	4	82.9200	14.1625	1.0643	3.9368
Jaw	1	75.0000	17.4490	0.8347	10.7532
Jaw	2	74.8100	16.3908	0.8123	10.6994
Jaw	3	74.1550	17.6026	0.8611	11.8263
Jaw	4	73.2000	18.2315	0.8708	10.6410
Tongue	1	82.2500	17.7835	1.1371	2.0360
Tongue	2	84.1700	17.7850	1.1349	1.9355
Tongue	3	84.9900	18.8039	1.2124	1.9474
Tongue	4	84.4600	18.5610	1.0964	2.0597

Table 3. The macro (mg.kg^{-1}) elements present in the neck flesh, clean head, jaw and tongue sections of the second lot of samples.

Hake head	Macro elements (mg.kg^{-1})				
section	P	K	Ca	Mg	Na
Neck flesh	54.13	9.53	84.08	3.77	7.50
Clean head	63.26	6.66	111.34	2.91	10.18
Jaw	211.48	5.17	376.43	6.06	15.94
Tongue	23.46	5.24	34.89	1.83	5.87

Table 4. The trace (µg.kg^{-1}) elements present in the neck flesh, clean head, jaw and tongue sections of the second lot of samples.

Hake head	Trace elements (µg.kg^{-1})		
section	Zn	Pb	Fe
Neck flesh	141.28	142.67	128.87
Clean head	149.20	94.17	28.61
Jaw	199.53	182.59	665.10
Tongue	201.14	99.53	53.53

Appendix: 3

Table 1. Whole hake length (cm) and mass (kg); H & G hake mass (kg); hake head mass (kg), length (cm), breadth (cm) and height (cm) for each of the four categories of hake sampled on boat trip number 1.

Category	Hake number	Hake length (cm)	Hake mass (kg)	H & G hake mass (kg)	Head mass (kg)	Head length (cm)	Head breadth (cm)	Head height (cm)
1	1	33.00	0.150	0.100	0.05	9.00	3.50	5.00
1	2	37.00	0.350	0.100	0.05	10.05	5.00	5.30
1	3	35.00	0.250	0.150	0.05	10.00	4.50	5.50
1	4	35.50	0.300	0.150	0.10	11.50	3.50	5.50
1	5	33.00	0.250	0.150	0.10	9.50	3.50	6.00
1	6	35.50	0.300	0.150	0.10	10.50	3.50	5.50
1	7	35.00	0.350	0.200	0.10	10.50	4.00	5.50
1	8	34.50	0.250	0.200	0.05	9.50	3.50	5.50
1	9	35.00	0.250	0.150	0.10	9.50	3.50	4.50
1	10	36.00	0.300	0.200	0.10	10.05	4.50	6.00
1	11	34.00	0.250	0.150	0.10	9.50	4.00	5.50
1	12	35.50	0.250	0.150	0.10	9.50	3.50	5.00
1	13	37.00	0.350	0.150	0.10	9.50	4.00	6.00
1	14	37.00	0.250	0.150	0.05	10.00	3.50	6.50
1	15	33.50	0.250	0.150	0.10	9.00	3.50	5.00
1	16	34.50	0.350	0.150	0.10	9.50	3.50	6.00
1	17	36.50	0.300	0.150	0.05	9.50	3.50	6.00
1	18	37.00	0.350	0.150	0.05	9.50	4.00	5.00
1	19	36.50	0.300	0.150	0.10	9.00	3.50	5.00
1	20	34.00	0.250	0.150	0.05	8.50	3.50	5.50
1	21	31.00	0.250	0.100	0.05	8.50	3.00	5.50
1	22	36.00	0.350	0.200	0.10	9.50	4.00	5.50
2	23	52.00	0.750	0.350	0.15	14.50	6.30	7.70
2	24	40.50	0.350	0.200	0.10	11.00	5.00	6.50
2	25	45.00	0.700	0.450	0.15	12.30	5.50	7.00
2	26	52.50	0.800	0.450	0.20	15.00	6.00	8.00
2	27	43.00	0.600	0.300	0.05	12.50	5.50	7.00
2	28	44.00	0.500	0.250	0.20	12.50	5.00	6.00
2	29	45.00	0.550	0.300	0.15	11.00	5.50	7.00
2	30	41.00	0.500	0.250	0.10	13.00	4.50	6.00
2	31	38.00	0.350	0.200	0.10	11.00	4.00	6.00
2	32	44.00	0.350	0.250	0.05	13.00	4.50	7.00
2	33	41.00	0.600	0.350	0.10	11.50	4.50	7.00
2	34	38.00	0.350	0.150	0.10	11.00	4.00	5.80
2	35	47.00	0.600	0.350	0.20	14.00	5.00	7.50
2	36	41.00	0.350	0.100	0.05	12.00	5.00	7.00
2	37	52.00	0.900	0.550	0.25	14.00	6.00	9.00
2	38	43.00	0.550	0.300	0.15	11.00	4.50	7.00

Table 1. (continued)

2	39	38.00	0.300	0.200	0.15	10.50	4.00	6.00
2	40	46.00	0.500	0.350	0.10	11.50	4.00	6.00
2	41	51.50	1.000	0.550	0.35	13.50	5.50	9.00
2	42	40.00	0.400	0.250	0.10	10.05	4.50	6.00
2	43	38.00	0.350	0.250	0.10	10.50	4.50	6.00
2	44	41.00	0.350	0.200	0.10	11.00	4.00	5.50
2	45	48.05	0.800	0.450	0.25	13.00	6.00	9.00
2	46	43.05	0.450	0.150	0.05	10.50	4.50	5.00
2	47	37.50	0.250	0.150	0.05	9.50	3.50	5.50
2	48	39.00	0.400	0.250	0.10	10.00	4.00	6.00
2	49	40.50	0.450	0.250	0.15	10.00	4.00	6.50
2	50	42.00	0.500	0.300	0.10	11.00	4.50	6.00
2	51	49.00	0.750	0.400	0.15	12.00	5.00	8.00
2	52	41.00	0.400	0.250	0.10	10.50	4.00	6.50
2	53	43.00	0.350	0.200	0.10	10.50	4.50	6.50
2	54	42.50	0.400	0.250	0.10	11.00	4.00	6.50
2	55	41.00	0.400	0.250	0.10	10.50	4.00	6.50
2	56	38.00	0.350	0.250	0.05	10.00	4.00	6.50
2	57	44.00	0.500	0.250	0.05	10.50	4.50	7.50
2	58	39.00	0.300	0.200	0.05	10.00	4.00	5.50
2	59	37.50	0.300	0.150	0.05	9.50	3.50	6.00
2	60	40.50	0.400	0.250	0.10	10.00	4.00	6.00
2	61	41.00	0.350	0.250	0.05	11.00	4.50	6.50
2	62	48.00	0.750	0.450	0.15	13.50	5.00	7.50
2	63	48.00	0.700	0.300	0.15	12.00	5.00	8.00
2	64	40.50	0.400	0.250	0.10	11.00	4.00	7.00
2	65	40.50	0.350	0.200	0.05	10.50	4.00	6.00
2	66	40.50	0.500	0.250	0.10	10.50	4.00	6.50
2	67	42.00	0.500	0.300	0.15	11.00	4.50	7.50
2	68	42.00	0.500	0.250	0.10	10.00	4.00	6.50
2	69	36.50	0.300	0.150	0.05	9.00	4.00	5.00
2	70	39.00	0.350	0.200	0.05	10.50	4.00	6.50
2	71	40.50	0.400	0.200	0.10	11.00	3.50	6.00
2	72	38.50	0.350	0.200	0.10	10.50	4.00	6.50
2	73	45.00	0.350	0.250	0.05	11.50	4.00	6.00
2	74	38.50	0.300	0.200	0.05	10.00	4.00	6.00
2	75	42.00	0.400	0.250	0.05	10.50	3.50	6.50
2	76	40.50	0.350	0.150	0.05	10.50	4.50	6.50
2	77	47.50	0.700	0.400	0.15	12.50	5.00	8.50
2	78	40.50	0.350	0.250	0.10	10.50	3.50	6.00
2	79	45.00	0.600	0.250	0.10	12.00	4.50	7.50
2	80	48.00	0.600	0.300	0.15	12.50	5.00	8.00
2	81	45.00	0.500	0.250	0.10	11.50	4.50	7.50
2	82	37.50	0.250	0.150	0.05	9.50	3.50	5.50
2	83	39.50	0.300	0.150	0.05	10.50	4.00	6.50
2	84	40.00	0.300	0.150	0.05	10.00	4.00	6.50
2	85	47.00	0.550	0.250	0.10	11.50	4.50	7.50
2	86	45.00	0.500	0.200	0.10	11.00	5.00	7.00
2	87	44.00	0.400	0.200	0.10	11.00	5.00	7.00

Table 1. (continued)

2	88	53.00	0.850	0.350	0.15	13.00	5.50	9.00
2	89	41.00	0.350	0.150	0.05	10.50	4.50	6.00
2	90	41.00	0.350	0.150	0.05	10.50	4.50	6.50
2	91	42.00	0.450	0.150	0.10	11.00	4.50	7.00
2	92	47.00	0.500	0.200	0.10	12.50	4.50	6.50
2	93	50.00	0.750	0.200	0.10	11.50	6.00	8.00
2	94	40.50	0.300	0.150	0.05	10.50	4.00	6.00
3	95	55.00	1.150	0.650	0.30	15.00	5.50	10.00
3	96	57.50	1.250	0.650	0.30	15.50	6.50	10.00
3	97	61.00	1.750	0.900	0.45	16.00	7.00	11.50
3	98	60.50	1.500	0.800	0.40	15.50	6.50	11.00
3	99	58.00	1.250	0.700	0.30	15.00	6.00	9.00
3	100	54.00	1.100	0.650	0.30	14.50	5.50	9.00
3	101	60.00	1.400	0.800	0.35	15.50	6.00	10.50
3	102	58.00	1.250	0.750	0.30	15.50	6.50	10.50
3	103	54.00	1.100	0.600	0.20	13.50	6.00	10.00
3	104	70.00	2.150	1.250	0.55	20.50	7.50	11.00
3	105	65.00	2.100	1.150	0.55	17.50	8.50	12.50
3	106	68.50	2.500	1.250	0.75	19.50	9.00	13.00
3	107	70.00	2.050	1.150	0.60	19.00	8.50	11.50
3	108	68.00	1.650	1.000	0.50	18.00	7.50	12.50
3	109	58.50	1.350	0.750	0.35	15.50	7.00	11.00
3	110	58.50	1.150	0.600	0.25	15.00	6.00	10.50
3	111	65.00	1.800	1.000	0.35	18.00	7.00	12.00
4	112	68.00	2.150	1.250	0.65	16.00	7.50	13.00
4	113	80.00	3.250	2.000	1.10	21.00	10.00	13.00
4	114	72.00	2.750	1.500	1.10	20.00	10.00	14.00
4	115	86.00	4.250	2.500	1.35	23.00	10.00	15.50

Table 2. Whole hake length (cm) and mass (kg); H & G hake mass (kg); hake head mass (kg), length (cm), breadth (cm) and height (cm) for each of the four categories of hake sampled on boat trip number 2.

Category	Hake number	Hake length (cm)	Hake mass (kg)	H & G hake mass (kg)	Head mass (kg)	Head length (cm)	Head breadth (cm)	Head height (cm)
1	1	28.7	0.185	0.115	0.065	7.6	3.2	4.5
1	2	32.1	0.240	0.150	0.080	8.5	3.5	5.5
1	3	33.5	0.245	0.160	0.080	9.0	4.0	5.5
1	4	31.2	0.210	0.140	0.080	8.5	4.5	5.5
1	5	35.3	0.300	0.195	0.105	9.2	4.2	6.2
1	6	33.2	0.255	0.160	0.090	8.9	3.6	5.2
1	7	34.5	0.310	0.205	0.110	9.0	4.6	5.7
1	8	32.5	0.260	0.160	0.105	8.7	4.0	5.3
1	9	36.5	0.340	0.225	0.130	9.5	4.5	6.5
1	10	32.5	0.260	0.155	0.100	9.2	4.2	5.5
1	11	32.0	0.245	0.155	0.100	8.6	4.3	5.6
1	12	32.5	0.260	0.175	0.095	8.9	4.3	5.5

Table 2. (continued)

1	13	35.0	0.310	0.195	0.115	9.1	4.3	6.0
1	14	33.5	0.305	0.205	0.105	9.2	4.5	5.7
1	15	35.5	0.385	0.240	0.115	9.5	5.0	6.2
1	16	36.5	0.315	0.215	0.115	10.1	4.6	6.0
1	17	32.2	0.260	0.170	0.090	9.2	4.2	6.2
1	18	33.0	0.255	0.155	0.100	9.0	4.5	6.0
1	19	33.5	0.310	0.205	0.110	9.2	4.5	6.2
1	20	29.5	0.185	0.120	0.080	8.0	4.0	5.5
1	21	32.5	0.245	0.160	0.085	8.2	4.2	5.5
1	22	30.5	0.180	0.135	0.075	8.1	3.7	5.0
1	23	35.0	0.280	0.190	0.105	9.0	4.0	5.5
1	24	30.5	0.230	0.145	0.080	8.0	4.0	5.5
1	25	34.5	0.330	0.215	0.115	9.5	5.0	5.7
1	26	32.0	0.230	0.150	0.085	8.5	4.0	5.0
1	27	35.2	0.350	0.230	0.120	9.5	4.5	6.5
1	28	32.0	0.250	0.160	0.095	8.7	4.0	5.5
1	29	35.0	0.325	0.220	0.105	9.5	5.0	6.0
1	30	31.5	0.225	0.150	0.075	9.0	4.0	5.0
1	31	32.2	0.250	0.155	0.085	8.5	4.5	5.5
1	32	32.5	0.225	0.150	0.085	8.5	4.5	5.5
1	33	36.5	0.375	0.250	0.125	10.0	5.0	6.0
1	34	28.0	0.175	0.105	0.065	8.0	3.5	5.0
1	35	31.2	0.215	0.140	0.080	8.0	4.0	5.0
1	36	29.0	0.180	0.110	0.065	8.0	3.5	5.5
1	37	33.7	0.260	0.185	0.090	9.5	4.0	5.0
1	38	27.5	0.165	0.095	0.065	7.7	3.5	5.0
1	39	28.5	0.190	0.125	0.065	7.5	3.5	4.5
1	40	25.5	0.135	0.080	0.060	7.0	3.0	4.5
1	41	32.0	0.225	0.155	0.085	8.5	4.0	5.0
1	42	30.5	0.220	0.140	0.080	8.5	4.0	5.0
1	43	34.0	0.270	0.175	0.090	9.5	4.0	5.2
1	44	30.5	0.205	0.135	0.075	8.5	4.0	5.5
1	45	31.5	0.230	0.150	0.090	8.5	4.0	5.5
1	46	25.5	0.125	0.080	0.055	7.5	3.5	4.5
1	47	34.0	0.300	0.200	0.100	9.5	4.0	6.0
2	48	45.50	0.700	0.445	0.240	13.00	7.00	7.50
2	49	38.50	0.480	0.315	0.155	10.50	5.50	6.50
2	50	40.00	0.500	0.330	0.180	11.00	5.50	6.50
2	51	44.00	0.720	0.465	0.240	12.00	6.00	7.50
2	52	45.50	0.750	0.480	0.235	12.50	5.50	8.00
2	53	38.50	0.480	0.325	0.160	10.50	5.00	6.00
2	54	45.00	0.685	0.455	0.230	12.00	6.50	7.50
2	55	40.00	0.500	0.330	0.165	10.50	5.50	7.00
2	56	44.00	0.725	0.485	0.245	12.50	7.00	8.00
2	57	37.50	0.425	0.275	0.130	10.50	5.00	6.00
2	58	40.00	0.525	0.350	0.155	11.00	5.50	6.50
2	59	41.50	0.650	0.420	0.210	11.00	6.00	7.50
2	60	40.00	0.420	0.270	0.165	11.50	5.00	6.50
2	61	40.50	0.525	0.350	0.170	11.00	5.50	6.50
2	62	39.00	0.500	0.330	0.165	10.50	5.00	6.50
2	63	40.00	0.565	0.380	0.170	11.00	6.00	7.00
2	64	37.50	0.400	0.250	0.135	10.00	4.50	6.50
2	65	38.00	0.450	0.295	0.150	10.00	5.00	6.50
2	66	46.50	0.750	0.500	0.240	13.00	6.00	7.50
2	67	42.00	0.570	0.390	0.170	11.50	5.50	6.50

Table 2. (continued)

2	68	37.00	0.370	0.225	0.145	10.00	4.50	6.50
2	69	43.00	0.570	0.400	0.190	11.50	5.50	6.50
2	70	38.00	0.420	0.275	0.135	10.00	5.00	6.00
2	71	38.00	0.380	0.245	0.140	10.50	5.20	6.00
2	72	45.00	0.720	0.455	0.225	12.00	6.00	7.50
2	73	41.00	0.465	0.305	0.160	11.00	5.00	6.50
2	74	45.00	0.600	0.390	0.190	11.50	5.50	6.50
2	75	39.50	0.490	0.315	0.155	11.00	5.00	6.00
2	76	39.00	0.440	0.265	0.140	9.50	4.50	6.50
2	77	45.50	0.680	0.450	0.225	12.00	6.00	7.00
2	78	43.00	0.625	0.410	0.210	12.00	5.00	7.00
2	79	39.50	0.465	0.310	0.155	10.00	5.00	6.50
2	80	37.00	0.340	0.215	0.120	9.50	4.50	5.50
2	81	49.00	0.845	0.555	0.285	12.50	6.00	8.00
2	82	47.00	0.745	0.480	0.240	12.50	6.00	7.50
2	83	42.50	0.610	0.400	0.205	11.00	6.00	7.00
2	84	47.50	0.715	0.480	0.240	12.50	6.00	7.50
2	85	46.00	0.640	0.435	0.205	12.00	5.50	6.50
2	86	40.00	0.460	0.300	0.160	10.00	5.00	6.50
2	87	40.00	0.460	0.310	0.150	10.00	4.50	6.50
2	88	40.00	0.470	0.300	0.160	10.50	4.50	6.50
2	89	39.00	0.420	0.250	0.165	10.50	4.50	7.00
2	90	39.50	0.450	0.300	0.160	11.00	5.00	7.00
2	91	41.00	0.500	0.320	0.160	10.50	5.00	7.00
2	92	76.00	0.740	0.500	0.240	13.00	5.50	7.50
2	93	45.00	0.820	0.480	0.230	12.00	5.00	8.00
2	94	46.00	0.750	0.480	0.240	12.00	6.00	7.50
2	95	40.00	0.490	0.335	0.150	11.00	5.00	7.00
2	96	47.50	0.840	0.550	0.270	13.00	5.50	8.00
2	97	37.50	0.365	0.235	0.120	10.00	4.50	6.50
2	98	48.00	0.840	0.550	0.240	12.50	5.00	6.50
2	99	44.00	0.650	0.450	0.200	12.00	5.00	7.00
2	100	43.50	0.600	0.400	0.180	12.00	5.00	7.00
3	101	59.50	2.000	0.960	0.570	16.50	8.00	9.00
3	102	64.50	2.300	1.270	0.740	19.00	8.00	10.00
3	103	56.50	1.275	0.805	0.455	16.00	8.00	9.00
3	104	61.00	1.720	1.800	0.600	17.50	8.00	9.00
3	105	64.00	2.170	1.290	0.725	17.50	9.00	11.00
3	106	67.50	2.000	1.210	0.725	18.50	8.00	9.50
3	107	58.50	1.590	0.900	0.510	15.50	7.50	10.00
3	108	61.00	1.920	1.170	0.650	17.50	8.00	10.00
3	109	60.00	1.590	0.955	0.620	18.00	9.00	10.00
3	110	56.00	1.430	0.900	0.485	15.50	8.00	9.00
3	111	61.50	1.810	1.090	0.685	18.00	9.50	11.00
3	112	56.00	1.580	0.980	0.565	16.00	8.00	9.00
3	113	60.00	1.555	0.930	0.580	16.50	7.50	9.50
3	114	70.50	2.595	1.630	0.895	20.00	8.50	12.00
3	115	59.50	1.740	1.010	0.655	18.00	8.50	9.50
3	116	67.00	2.400	1.490	0.845	19.00	9.00	11.00
3	117	65.00	2.000	1.180	0.770	19.50	9.00	10.00
3	118	61.50	1.715	1.010	0.555	16.50	8.50	9.50
3	119	61.00	1.735	1.090	0.610	17.00	8.00	11.00
3	120	60.50	1.900	1.065	0.755	18.00	9.00	11.00
3	121	66.00	2.330	1.330	0.890	18.50	9.00	12.00
3	122	61.00	1.935	1.130	0.650	17.00	9.00	10.00

Table 2. (continued)

3	123	62.50	1.975	1.170	0.720	17.00	8.00	9.50
3	124	59.50	1.690	1.025	0.590	17.50	8.00	11.00
3	125	62.00	1.950	1.205	0.685	17.50	8.00	11.00
3	126	70.00	2.520	1.570	0.850	19.50	9.00	12.00
3	127	58.50	1.750	0.955	0.510	16.00	7.50	9.50
3	128	58.00	1.650	1.000	0.565	16.00	8.00	10.00
3	129	63.00	1.930	1.245	0.610	17.00	8.00	9.50
3	130	61.50	2.120	1.225	0.680	17.00	8.00	11.00
3	131	63.00	2.550	1.185	0.760	18.50	9.00	12.00
3	132	58.00	1.500	0.920	0.550	16.50	8.00	10.00
3	133	62.50	1.960	1.220	0.600	17.50	8.00	9.50
3	134	60.50	1.640	1.010	0.610	17.00	8.00	11.00
3	135	56.50	1.385	0.785	0.550	17.00	8.00	10.00
3	136	65.50	2.190	1.315	0.780	18.50	9.00	10.00
3	137	62.00	1.680	1.000	0.650	17.00	8.50	10.00
3	138	62.50	2.170	1.200	0.750	18.00	8.50	10.00
3	139	64.00	2.200	1.340	0.730	18.00	8.00	11.00
3	140	66.50	2.100	1.210	0.660	17.00	8.50	10.00
3	141	61.50	1.805	1.130	0.580	17.00	8.00	10.50
3	142	58.50	1.910	1.140	0.580	17.00	8.00	11.00
3	143	65.00	2.020	1.170	0.750	18.50	8.00	10.00
3	144	61.50	2.070	1.250	0.750	18.00	9.00	10.50
3	145	63.50	2.100	1.250	0.780	18.50	10.00	11.00
4	146	77.00	4.500	2.750	1.520	24.50	10.50	15.00
4	147	82.50	6.250	2.750	1.880	26.00	11.00	14.00
4	148	74.00	4.250	2.045	1.110	22.00	10.50	12.50
4	149	79.00	5.500	2.590	1.460	22.00	10.00	13.00
4	150	86.00	6.500	2.610	1.965	24.00	11.00	15.00
4	151	80.50	4.250	2.220	1.570	24.00	12.00	14.50
4	152	81.00	5.500	2.580	1.640	23.00	12.00	15.00
4	153	77.00	5.250	2.500	1.460	23.00	12.00	15.00
4	154	81.00	5.000	2.570	1.610	24.00	11.00	15.00
4	155	87.50	6.000	2.615	1.825	25.00	11.00	14.00
4	156	78.00	4.000	2.125	1.290	23.00	11.00	13.00
4	157	82.50	5.750	2.615	1.540	24.00	10.00	15.00
4	158	81.00	5.250	2.430	1.550	23.00	10.00	14.00
4	159	76.50	4.750	2.220	1.360	21.00	10.00	15.00
4	160	76.50	4.750	2.160	1.420	24.00	11.00	15.00
4	161	81.00	5.000	2.580	1.650	25.00	11.00	15.00
4	162	88.00	6.500	2.620	2.080	26.00	12.00	16.00
4	163	79.00	5.250	2.470	1.635	25.00	10.00	15.00
4	164	86.00	4.500	2.390	1.720	26.00	11.00	14.00
4	165	80.00	4.500	2.500	1.390	24.00	10.00	15.00
4	166	76.00	4.000	2.310	1.090	21.00	10.00	12.00
4	167	77.50	4.250	2.430	1.215	21.00	10.00	12.00
4	168	80.00	4.750	2.310	1.400	23.00	12.00	13.00
4	169	84.00	5.000	2.580	1.620	26.00	11.00	15.00
4	170	79.00	4.000	2.160	1.190	22.00	9.00	13.00
4	171	83.00	5.750	2.600	1.785	24.00	12.00	15.00
4	172	80.00	4.500	2.185	1.440	23.00	10.50	13.00
4	173	79.00	4.250	2.160	1.400	23.00	10.00	15.00
4	174	77.00	4.000	2.180	1.280	22.00	10.00	14.00
4	175	86.00	5.000	2.610	1.490	23.00	10.00	13.00
4	176	78.00	4.500	2.320	1.315	23.00	9.00	14.00
4	177	75.00	4.500	2.020	1.200	22.00	9.00	12.00

Table 2. (continued)

4	178	85.00	5.750	2.600	1.730	24.00	10.00	14.00
4	179	74.00	3.750	1.925	1.045	20.00	10.00	13.00
4	180	79.00	5.250	2.470	1.635	25.00	10.00	15.00
4	181	74.00	3.500	2.310	1.030	21.00	10.00	12.00
4	182	95.00	5.250	2.610	2.095	28.00	11.00	15.00
4	183	77.00	3.750	2.300	1.370	24.00	11.00	15.00
4	184	72.00	3.500	1.830	1.010	21.00	10.00	12.00
4	185	87.00	6.250	2.620	2.010	26.00	13.00	16.00

Table 3. Whole hake length (cm) and mass (kg); H & G hake mass (kg); hake head mass (kg), length (cm), breadth (cm) and height (cm) for each of the four categories of hake sampled on boat trip number 3.

Category	Hake number	Hake length (cm)	Hake mass (kg)	H & G hake mass (kg)	Head mass (kg)	Head length (cm)	Head breadth (cm)	Head height (cm)
1	1	29.200	0.160	0.100	0.050	7.500	3.500	4.500
1	2	35.500	0.310	0.200	0.120	9.500	4.500	5.500
1	3	31.500	0.215	0.140	0.085	8.000	3.500	4.500
1	4	35.000	0.290	0.180	0.100	9.500	4.500	5.500
1	5	36.500	0.300	0.175	0.120	9.500	4.000	5.500
1	6	33.500	0.275	0.185	0.080	8.000	4.500	5.000
1	7	33.500	0.250	0.155	0.095	8.500	4.000	5.000
1	8	31.000	0.220	0.140	0.085	8.500	4.000	5.000
1	9	31.000	0.210	0.125	0.080	8.500	4.500	5.000
1	10	32.500	0.235	0.135	0.085	8.500	4.500	5.000
1	11	30.500	0.200	0.120	0.075	8.000	4.000	4.500
1	12	35.500	0.315	0.200	0.115	9.000	4.500	5.000
1	13	33.000	0.245	0.160	0.095	9.000	4.000	5.500
1	14	33.500	0.295	0.190	0.110	9.000	5.000	5.500
1	15	33.000	0.230	0.150	0.090	8.500	4.500	5.000
1	16	34.500	0.265	0.180	0.110	8.500	4.500	5.500
1	17	36.000	0.335	0.225	0.115	10.000	4.500	5.500
1	18	33.000	0.255	0.170	0.090	8.500	4.500	5.500
1	19	30.000	0.200	0.135	0.080	8.500	4.000	5.000
1	20	29.000	0.185	0.120	0.080	8.000	3.500	4.500
1	21	30.000	0.185	0.120	0.085	7.500	4.000	4.500
1	22	33.000	0.250	0.175	0.085	8.500	4.000	5.000
1	23	30.500	0.200	0.125	0.075	8.000	4.000	5.000
1	24	31.000	0.210	0.130	0.080	8.000	4.000	5.000
1	25	34.500	0.265	0.175	0.100	9.500	4.500	5.500
1	26	32.500	0.220	0.155	0.080	8.500	4.500	5.500
1	27	35.000	0.285	0.200	0.100	9.000	4.500	5.000
1	28	30.000	0.200	0.130	0.080	8.000	4.000	5.000
1	29	37.000	0.345	0.220	0.115	10.000	5.000	6.000
1	30	34.000	0.260	0.175	0.100	8.500	4.500	6.000
1	31	35.000	0.300	0.200	0.125	9.500	4.500	5.500
1	32	34.000	0.280	0.185	0.105	9.000	4.500	5.500
1	33	30.000	0.180	0.105	0.080	7.500	4.000	5.000

Table 3. (continued)

1	34	34.500	0.270	0.170	0.110	8.500	4.500	5.500
1	35	31.500	0.225	0.155	0.090	8.500	4.000	5.000
1	36	37.500	0.360	0.255	0.110	10.000	4.000	6.000
1	37	31.500	0.205	0.130	0.070	8.500	3.500	5.000
1	38	37.000	0.360	0.225	0.115	10.000	4.500	6.000
1	39	30.000	0.175	0.120	0.055	8.000	4.000	5.000
1	40	35.500	0.320	0.205	0.110	9.000	4.500	5.500
1	41	36.000	0.315	0.205	0.115	9.000	4.500	5.500
1	42	33.500	0.275	0.185	0.100	9.000	4.500	6.000
1	43	33.000	0.235	0.150	0.085	9.000	4.000	5.000
1	44	35.000	0.290	0.185	0.115	9.500	4.000	5.500
1	45	35.000	0.310	0.200	0.115	9.500	4.000	6.500
1	46	35.000	0.270	0.185	0.095	9.000	4.000	5.500
1	47	31.500	0.235	0.145	0.095	9.000	4.000	5.500
1	48	37.000	0.325	0.205	0.105	9.500	4.500	5.500
1	49	34.000	0.290	0.195	0.095	8.500	4.000	5.500
1	50	32.500	0.250	0.155	0.090	8.500	4.000	5.500
1	51	36.500	0.355	0.220	0.125	9.500	4.000	6.000
1	52	35.500	0.325	0.215	0.115	9.500	4.000	5.500
1	53	29.000	0.170	0.105	0.065	8.000	4.000	5.000
1	54	29.500	0.185	0.115	0.075	8.000	4.000	5.000
1	55	35.000	0.325	0.215	0.105	9.000	4.500	5.500
1	56	35.500	0.305	0.205	0.115	9.500	4.500	6.000
1	57	33.500	0.255	0.165	0.090	8.500	3.500	5.000
1	58	30.000	0.195	0.125	0.075	8.000	3.500	5.000
1	59	31.500	0.215	0.145	0.080	8.000	4.000	4.500
1	60	36.500	0.335	0.230	0.115	10.000	4.500	6.000
1	61	33.000	0.250	0.160	0.095	8.000	4.500	5.500
1	62	34.000	0.275	0.180	0.105	9.000	4.500	5.500
1	63	33.000	0.250	0.165	0.095	9.000	4.500	5.500
1	64	31.000	0.225	0.155	0.095	8.500	4.000	5.500
1	65	31.500	0.225	0.145	0.085	8.500	4.000	5.000
1	66	34.500	0.290	0.200	0.110	9.000	4.500	5.500
1	67	30.000	0.200	0.130	0.080	8.500	4.000	5.500
1	68	32.000	0.250	0.165	0.110	9.000	4.500	5.500
1	69	34.500	0.295	0.200	0.115	8.500	4.500	5.500
1	70	34.500	0.300	0.195	0.115	9.500	4.500	5.500
1	71	31.500	0.235	0.145	0.100	8.500	4.500	5.500
1	72	33.000	0.265	0.185	0.115	9.000	4.000	5.500
1	73	35.500	0.300	0.215	0.115	9.000	4.500	5.500
1	74	34.000	0.280	0.200	0.100	9.000	4.000	5.500
1	75	34.000	0.280	0.200	0.110	8.500	4.000	6.000
1	76	34.000	0.255	0.175	0.105	9.500	4.500	6.000
1	77	36.000	0.300	0.215	0.125	10.000	4.500	5.500
1	78	28.000	0.165	0.115	0.080	7.500	3.000	4.500
1	79	36.000	0.135	0.200	0.125	10.000	4.000	5.500
1	80	33.500	0.295	0.200	0.105	8.500	10.000	5.000
1	81	33.000	0.240	0.175	0.105	8.500	10.000	5.500
1	82	30.000	0.225	0.170	0.095	8.500	4.000	5.500
1	83	35.000	0.300	0.220	0.120	8.500	4.000	5.500
1	84	29.000	0.200	0.140	0.085	7.500	3.500	5.000
1	85	31.000	0.215	0.145	0.085	8.500	4.000	5.500
1	86	31.000	0.200	0.140	0.090	7.500	4.000	5.500
1	87	33.000	0.245	0.175	0.115	8.500	4.000	5.000
1	88	31.500	0.215	0.155	0.100	8.500	4.000	5.500

Table 3. (continued)

1	89	33.000	0.245	0.170	0.100	9.000	4.500	6.000
1	90	31.500	0.245	0.155	0.095	9.000	4.000	5.500
1	91	30.500	0.185	0.115	0.080	8.000	3.500	4.500
1	92	28.500	0.160	0.100	0.075	8.000	3.500	5.000
1	93	32.500	0.225	0.145	0.095	8.500	4.000	5.000
1	94	31.500	0.200	0.125	0.085	8.500	3.500	5.000
1	95	29.000	0.175	0.110	0.075	8.000	4.000	5.000
1	96	29.500	0.185	0.125	0.075	8.000	3.500	5.000
1	97	29.500	0.185	0.115	0.075	8.500	3.500	5.000
1	98	30.000	0.205	0.145	0.085	8.000	4.000	5.000
1	99	29.500	0.165	0.100	0.080	8.000	3.500	5.000
1	100	29.000	0.175	0.115	0.075	8.000	3.500	5.000
1	101	28.500	0.165	0.110	0.060	7.500	3.500	5.000
1	102	33.500	0.265	0.175	0.100	9.500	4.000	5.500
1	103	29.000	0.165	0.120	0.065	8.000	3.500	5.000
1	104	30.000	0.175	0.115	0.075	8.500	4.000	5.500
1	105	29.500	0.185	0.135	0.080	8.500	4.000	5.000
1	106	30.000	0.200	0.125	0.080	8.500	3.500	5.000
1	107	28.000	0.175	0.115	0.070	8.000	4.000	4.500
1	108	27.500	0.155	0.090	0.085	8.000	4.000	5.000
1	109	28.500	0.165	0.105	0.080	8.500	3.500	5.000
1	110	32.000	0.235	0.155	0.110	9.000	4.500	5.500
1	111	31.000	0.205	0.135	0.085	8.500	3.500	5.500
1	112	33.000	0.240	0.160	0.100	9.000	4.500	5.500
1	113	33.500	0.245	0.160	0.090	8.500	4.000	5.000
1	114	26.500	0.160	0.110	0.080	7.000	3.500	4.500
1	115	28.000	0.165	0.120	0.075	7.500	3.500	5.000
1	116	29.000	0.190	0.130	0.080	7.500	3.500	4.500
1	117	28.000	0.175	0.130	0.080	7.000	3.500	5.000
1	118	28.000	0.165	0.120	0.080	7.500	3.500	4.000
1	119	28.000	0.175	0.125	0.080	7.500	3.500	5.000
1	120	27.000	0.165	0.120	0.075	7.000	3.500	5.000
1	121	27.000	0.170	0.110	0.080	7.500	3.500	5.000
1	122	27.500	0.160	0.110	0.080	7.500	3.500	4.500
1	123	28.000	0.170	0.120	0.075	7.500	3.500	5.000
1	124	29.500	0.210	0.150	0.095	8.000	3.500	5.000
1	125	28.500	0.175	0.125	0.080	7.500	3.500	5.000
1	126	29.500	0.210	0.140	0.100	8.000	4.000	5.000
1	127	28.000	0.155	0.115	0.075	8.000	3.500	4.000
1	128	28.500	0.195	0.125	0.080	7.500	3.500	4.500
1	129	31.500	0.200	0.150	0.085	8.000	3.500	5.000
1	130	30.500	0.220	0.145	0.090	8.000	4.000	5.000
1	131	29.000	0.185	0.120	0.090	7.500	3.500	5.000
1	132	31.000	0.210	0.155	0.100	8.000	3.500	4.000
1	133	29.500	0.200	0.145	0.090	7.500	3.500	4.500
1	134	31.500	0.200	0.125	0.075	8.500	4.000	5.000
1	135	33.500	0.240	0.175	0.085	9.000	4.000	5.500
1	136	35.000	0.315	0.215	0.100	9.000	4.500	5.500
1	137	36.000	0.305	0.205	0.105	8.500	4.000	5.500
1	138	32.500	0.250	0.170	0.085	8.500	3.500	5.500
1	139	35.500	0.335	0.220	0.115	9.500	4.000	5.000
1	140	31.000	0.195	0.130	0.070	8.500	3.500	5.500
1	141	34.000	0.265	0.160	0.095	8.500	4.000	5.000
1	142	33.500	0.255	0.155	0.095	7.000	4.000	5.500
1	143	34.000	0.290	0.200	0.110	9.000	4.000	5.500

Table 3. (continued)

1	144	35.500	0.310	0.210	0.115	9.500	4.000	5.500
1	145	34.000	0.280	0.185	0.115	9.500	4.000	6.000
1	146	35.000	0.300	0.200	0.105	9.500	4.000	6.000
1	147	33.000	0.230	0.145	0.085	8.500	3.500	5.500
1	148	33.000	0.260	0.165	0.085	8.500	4.000	5.500
1	149	33.500	0.230	0.160	0.090	8.500	3.500	5.500
1	150	33.000	0.265	0.180	0.095	9.500	3.500	5.500
1	151	33.500	0.285	0.200	0.110	10.000	4.500	5.500
1	152	35.500	0.285	0.195	0.100	9.000	4.000	5.500
1	153	34.000	0.280	0.190	0.105	9.500	4.000	5.500
1	154	35.000	0.305	0.215	0.115	9.500	4.000	6.000
1	155	27.500	0.150	0.100	0.075	8.000	3.500	5.000
1	156	32.000	0.225	0.165	0.085	8.500	3.500	5.000
1	157	31.500	0.295	0.205	0.100	9.000	4.000	5.000
1	158	29.500	0.175	0.115	0.065	8.000	3.500	4.500
1	159	35.000	0.315	0.210	0.105	9.000	4.500	5.500
1	160	30.500	0.195	0.135	0.085	8.000	3.500	4.500
1	161	32.000	0.230	0.155	0.090	9.000	4.000	5.500
1	162	33.000	0.250	0.165	0.105	9.000	4.000	5.500
1	163	33.500	0.250	0.170	0.090	9.000	4.000	5.500
1	164	30.000	0.170	0.115	0.080	8.500	3.500	4.500
1	165	35.000	0.275	0.185	0.115	9.500	4.000	5.500
1	166	32.000	0.240	0.165	0.085	9.000	4.000	5.500
1	167	34.000	0.210	0.145	0.085	8.500	4.000	5.500
1	168	33.500	0.280	0.185	0.100	9.000	4.000	5.500
1	169	29.500	0.165	0.115	0.075	8.500	4.500	4.000
1	170	34.500	0.280	0.185	0.110	9.500	4.000	5.500
1	171	34.500	0.285	0.200	0.105	9.000	4.500	5.500
1	172	30.000	0.190	0.135	0.085	8.500	3.500	5.500
1	173	29.500	0.160	0.110	0.075	7.500	3.500	4.500
1	174	32.000	0.225	0.155	0.085	8.500	4.000	5.000
1	175	28.500	0.155	0.110	0.070	8.000	3.500	4.500
1	176	33.000	0.245	0.170	0.100	9.000	4.500	5.000
1	177	34.500	0.275	0.200	0.110	9.000	4.500	5.500
1	178	31.500	0.235	0.165	0.100	8.500	4.000	5.000
1	179	32.000	0.215	0.145	0.090	8.500	4.000	5.000
1	180	32.500	0.225	0.155	0.100	8.500	4.000	5.000
1	181	28.500	0.155	0.115	0.070	7.500	4.000	5.000
1	182	33.000	0.240	0.175	0.105	9.500	4.500	5.500
1	183	33.000	0.280	0.185	0.105	8.500	4.500	5.500
1	184	31.500	0.210	0.135	0.085	8.500	3.500	5.000
1	185	30.000	0.185	0.130	0.085	8.500	3.500	4.500
1	186	26.000	0.135	0.085	0.070	7.000	3.000	4.500
1	187	31.000	0.200	0.140	0.095	8.500	3.500	5.000
1	188	32.000	0.235	0.160	0.095	8.500	3.500	5.000
1	189	27.000	0.155	0.105	0.075	7.500	3.500	4.500
1	190	33.000	0.225	0.160	0.105	8.500	4.000	5.500
1	191	29.000	0.195	0.135	0.090	8.000	3.500	5.000
1	192	28.500	0.175	0.135	0.080	7.500	3.500	5.000
1	193	31.000	0.235	0.155	0.095	8.000	4.000	5.000
1	194	28.500	0.190	0.125	0.090	8.000	3.500	5.000
1	195	31.000	0.210	0.135	0.080	8.000	3.500	5.000
1	196	32.500	0.235	0.150	0.100	8.000	4.000	5.500
1	197	29.000	0.175	0.110	0.070	8.000	3.000	5.000
1	198	34.000	0.270	0.175	0.120	8.500	4.000	5.500

Table 3. (continued)

1	199	35.500	0.315	0.205	0.105	9.000	4.500	5.500
1	200	29.000	0.180	0.105	0.070	8.500	3.500	5.000
1	201	30.500	0.205	0.130	0.080	8.000	3.500	5.000
1	202	29.500	0.180	0.120	0.080	8.500	3.500	5.000
1	203	31.500	0.210	0.140	0.080	8.000	3.500	5.500
1	204	28.500	0.180	0.125	0.080	7.500	4.000	5.000
1	205	32.500	0.225	0.160	0.085	8.000	4.000	5.500
1	206	31.000	0.210	0.150	0.085	8.000	3.500	5.500
1	207	26.500	0.150	0.100	0.070	7.500	3.500	5.500
1	208	33.000	0.240	0.170	0.100	8.500	4.500	5.500
1	209	33.500	0.250	0.165	0.105	8.500	4.500	5.500
1	210	31.500	0.235	0.160	0.095	8.000	4.000	5.000
1	211	33.000	0.265	0.170	0.105	8.500	4.000	5.500
1	212	28.000	0.145	0.100	0.070	7.500	3.000	5.000
1	213	32.500	0.255	0.175	0.100	9.000	4.000	5.500
1	214	32.000	0.235	0.155	0.100	8.500	4.000	6.000
1	215	27.000	0.145	0.100	0.065	7.500	3.000	4.500
1	216	29.000	0.185	0.120	0.080	7.500	3.500	5.000
1	217	25.000	0.150	0.100	0.060	7.000	3.500	4.000
1	218	29.000	0.170	0.125	0.080	8.500	3.500	4.500
2	219	46.500	0.775	0.500	0.260	12.500	6.000	8.000
2	220	39.500	0.445	0.285	0.155	10.000	5.000	5.500
2	221	44.500	0.675	0.445	0.220	12.500	5.500	7.500
2	222	38.000	0.365	0.245	0.130	10.000	4.500	6.000
2	223	37.500	0.390	0.255	0.140	10.000	4.500	6.000
2	224	47.000	0.840	0.550	0.290	13.500	6.000	8.500
2	225	51.500	1.015	0.665	0.310	12.500	6.500	9.000
2	226	39.000	0.430	0.260	0.145	9.500	10.500	6.500
2	227	41.500	0.510	0.350	0.155	10.500	10.500	6.500
2	228	42.500	0.545	0.385	0.165	11.000	5.000	6.000
2	229	40.000	0.440	0.280	0.155	10.000	4.500	6.500
2	230	36.000	0.375	0.255	0.125	9.500	4.500	5.500
2	231	36.500	0.370	0.265	0.135	9.000	5.000	6.000
2	232	49.000	0.725	0.480	0.235	13.000	6.000	8.000
2	233	37.000	0.385	0.260	0.145	10.000	5.000	6.500
2	234	39.000	0.425	0.265	0.145	10.000	5.000	6.000
2	235	38.000	0.400	0.255	0.135	10.000	6.000	7.000
2	236	41.500	0.465	0.305	0.160	11.000	5.500	6.500
2	237	43.000	0.615	0.380	0.220	10.500	6.000	7.500
2	238	53.000	1.040	0.655	0.390	14.500	7.000	8.500
2	239	44.500	0.615	0.415	0.215	11.500	6.000	7.500
2	240	50.000	0.925	0.590	0.315	13.000	6.500	8.000
2	241	44.500	0.605	0.405	0.200	11.500	5.500	6.500
2	242	47.000	0.805	0.500	0.300	13.500	6.500	8.500
2	243	51.500	0.975	0.605	0.315	14.500	6.000	9.000
2	244	40.000	0.405	0.260	0.145	10.500	4.500	6.500
2	245	39.000	0.390	0.270	0.130	10.000	4.000	6.000
2	246	39.500	0.435	0.295	0.145	10.000	4.000	6.000
2	247	37.500	0.415	0.275	0.145	10.000	4.500	6.500
2	248	37.500	0.395	0.265	0.120	9.500	4.000	6.500
2	249	38.500	0.385	0.255	0.135	10.000	4.000	6.000
2	250	46.000	0.635	0.435	0.215	11.500	5.500	6.500
2	251	40.000	0.475	0.315	0.145	10.500	4.500	6.500
2	252	45.000	0.680	0.435	0.245	11.500	5.500	7.500
2	253	39.500	0.405	0.265	0.125	10.500	4.500	5.500

Table 3. (continued)

2	254	41.000	0.465	0.310	0.150	10.500	4.500	6.500
2	255	37.500	0.335	0.225	0.120	9.000	4.000	6.000
2	256	40.500	0.485	0.315	0.165	10.500	4.500	6.500
2	257	44.000	0.605	0.380	0.235	12.500	5.000	8.000
2	258	37.000	0.355	0.235	0.130	10.000	4.000	5.500
2	259	37.500	0.375	0.235	0.155	10.000	4.000	6.500
2	260	47.500	0.795	0.525	0.255	12.500	6.000	7.500
2	261	51.500	0.990	0.635	0.315	14.000	6.500	8.500
2	262	53.500	1.215	0.765	0.380	14.000	7.000	9.000
2	263	51.000	0.940	0.585	0.310	13.000	6.500	8.500
2	264	41.000	0.515	0.330	0.195	11.500	5.500	7.500
2	265	43.000	0.575	0.375	0.205	11.000	5.000	7.500
2	266	39.000	0.445	0.280	0.170	10.500	5.000	6.500
2	267	46.500	0.730	0.475	0.240	12.500	6.000	8.000
2	268	45.000	0.595	0.390	0.215	12.000	5.500	6.000
2	269	43.000	0.640	0.420	0.225	11.000	6.000	7.000
2	270	53.500	1.085	0.740	0.315	13.500	6.000	8.000
2	271	43.500	0.635	0.415	0.185	11.000	5.000	7.500
2	272	49.500	0.855	0.500	0.295	13.000	6.000	8.000
2	273	48.500	0.775	0.500	0.245	12.500	4.500	7.500
2	274	43.000	0.575	0.375	0.195	11.000	5.500	6.500
2	275	52.000	0.965	0.655	0.285	13.000	6.000	7.500
2	276	43.000	0.520	0.345	0.190	10.500	5.000	6.000
2	277	48.500	0.800	0.515	0.260	12.500	5.500	7.500
2	278	47.000	0.720	0.470	0.265	13.000	5.000	7.500
2	279	47.000	0.845	0.530	0.300	13.000	6.000	8.000
2	280	42.000	0.520	0.350	0.185	11.500	5.500	7.000
2	281	52.000	0.785	0.500	0.290	13.500	5.000	8.000
2	282	53.500	0.990	0.660	0.335	14.000	6.000	8.500
2	283	41.500	0.540	0.365	0.190	11.000	5.000	7.000
2	284	47.000	0.825	0.530	0.280	12.000	6.000	8.000
2	285	45.000	0.730	0.475	0.265	12.000	6.000	8.000
2	286	44.500	0.590	0.415	0.205	11.500	5.500	6.500
2	287	49.500	0.990	0.615	0.295	12.500	6.000	9.000
2	288	53.500	1.060	0.655	0.345	14.500	7.000	9.500
2	289	50.000	0.965	0.600	0.315	13.500	6.000	8.500
2	290	46.500	0.745	0.480	0.275	12.500	5.000	8.000
2	291	49.000	0.865	0.575	0.280	13.000	5.500	8.000
2	292	53.000	0.985	0.615	0.330	13.500	6.000	8.500
2	293	51.000	0.955	0.610	0.315	13.500	6.000	9.000
2	294	52.000	1.065	0.685	0.325	14.000	6.000	8.500
2	295	48.000	0.730	0.485	0.245	12.000	5.000	7.000
2	296	49.500	0.860	0.555	0.285	13.000	5.500	7.500
2	297	46.500	0.755	0.485	0.285	12.500	5.500	8.000
2	298	52.000	0.975	0.620	0.355	14.500	6.000	8.000
2	299	39.500	0.485	0.300	0.185	10.000	5.000	6.500
2	300	43.000	0.625	0.415	0.215	11.500	5.000	7.500
2	301	46.000	0.755	0.500	0.245	12.000	5.500	7.500
2	302	43.000	0.625	0.415	0.195	10.500	5.000	7.000
2	303	46.000	0.710	0.435	0.255	11.500	5.500	7.500
2	304	48.500	0.805	0.535	0.265	13.000	5.500	7.500
2	305	37.000	0.405	0.275	0.135	10.000	5.000	6.000
2	306	49.500	0.935	0.625	0.300	13.000	6.000	8.500
2	307	45.000	0.825	0.470	0.270	12.000	4.500	7.500
2	308	47.500	0.860	0.555	0.300	13.000	5.500	8.000

Table 3. (continued)

2	309	52.000	0.995	0.680	0.300	13.000	6.500	8.500
2	310	48.000	0.885	0.515	0.335	13.000	6.500	8.500
2	311	51.000	1.110	0.665	0.355	14.500	6.500	8.000
2	312	50.500	0.850	0.580	0.270	12.500	6.000	7.500
2	313	53.500	1.090	0.650	0.370	13.500	6.500	9.000
2	314	53.000	1.295	0.805	0.435	14.500	6.500	9.000
2	315	46.000	0.755	0.485	0.270	12.500	6.000	8.000
2	316	48.000	0.725	0.485	0.240	12.500	5.500	7.000
2	317	50.500	0.910	0.600	0.290	12.500	6.000	8.000
2	318	48.500	0.910	0.505	0.325	13.000	5.500	8.000
2	319	49.000	0.905	0.565	0.335	14.500	6.500	8.500
2	320	46.000	0.735	0.500	0.240	12.000	5.500	8.000
2	321	47.000	0.690	0.450	0.235	12.500	5.500	8.000
2	322	47.500	0.720	0.465	0.245	12.500	6.000	8.000
2	323	53.500	1.125	0.720	0.370	14.000	6.500	9.000
2	324	46.000	0.630	0.395	0.200	11.000	5.000	7.000
2	325	52.500	0.920	0.615	0.300	14.000	6.000	8.500
2	326	48.500	0.670	0.450	0.225	12.000	5.500	7.500
2	327	44.000	0.585	0.375	0.210	12.000	5.500	7.000
2	328	44.500	0.635	0.425	0.215	12.000	5.500	7.500
2	329	46.000	0.630	0.415	0.215	12.500	4.500	7.500
2	330	53.500	1.025	0.680	0.340	14.500	6.500	8.500
2	331	49.000	0.835	0.575	0.265	13.000	5.500	8.000
2	332	48.000	0.745	0.490	0.265	13.000	5.500	7.500
2	333	44.000	0.665	0.420	0.225	12.000	6.000	7.500
2	334	44.500	0.660	0.450	0.225	12.000	5.000	7.500
2	335	43.000	0.535	0.365	0.180	12.000	5.000	6.500
2	336	40.500	0.470	0.320	0.165	11.500	4.500	6.500
2	337	43.000	0.535	0.365	0.185	11.500	4.500	6.500
2	338	44.500	0.655	0.435	0.215	11.500	4.500	7.000
2	339	48.500	0.845	0.545	0.275	13.000	5.500	7.500
2	340	52.500	1.060	0.640	0.335	14.000	6.500	9.500
2	341	52.000	0.925	0.625	0.300	14.500	5.500	8.500
2	342	51.500	0.900	0.610	0.295	14.000	6.000	8.500
2	343	52.000	1.070	0.670	0.325	14.000	7.000	8.500
2	344	52.500	1.070	0.610	0.315	13.500	5.500	8.000
2	345	48.000	0.735	0.500	0.235	12.500	5.500	8.000
2	346	47.000	0.775	0.515	0.250	12.500	5.000	7.500
2	347	50.000	0.840	0.575	0.275	13.000	6.000	8.000
2	348	49.500	0.880	0.600	0.275	13.000	6.000	7.500
2	349	47.500	0.725	0.500	0.245	12.500	5.500	7.500
2	350	51.500	0.800	0.530	0.290	14.000	6.000	7.500
2	351	52.000	1.065	0.685	0.365	14.000	6.000	9.500
2	352	53.500	1.080	0.730	0.355	13.500	6.500	8.500
2	353	45.000	0.690	0.450	0.235	11.500	6.500	8.000
2	354	46.000	0.620	0.405	0.235	12.500	5.000	7.000
2	355	48.500	0.790	0.530	0.265	13.000	5.500	8.000
2	356	51.000	0.870	0.590	0.290	13.000	6.000	8.500
2	357	45.500	0.665	0.430	0.225	11.500	5.500	7.500
2	358	45.500	0.650	0.435	0.215	12.000	5.500	7.500
2	359	51.000	1.020	0.675	0.325	13.500	6.500	8.000
2	360	50.500	0.910	0.605	0.290	13.000	6.500	8.000
2	361	50.500	0.890	0.605	0.270	13.000	6.500	8.000
2	362	41.500	0.485	0.335	0.175	11.000	5.500	7.500
2	363	45.000	0.690	0.445	0.235	11.500	5.500	7.500

Table 3. (continued)

2	364	49.000	0.885	0.600	0.295	12.500	6.500	8.500
2	365	40.500	0.465	0.315	0.170	10.000	5.000	7.000
2	366	41.500	0.510	0.350	0.180	10.000	5.500	7.500
2	367	47.000	0.800	0.540	0.250	12.500	5.500	7.500
2	368	47.000	0.670	0.450	0.230	13.000	5.500	7.500
2	369	45.500	0.695	0.450	0.255	12.500	5.500	8.000
2	370	48.000	0.780	0.510	0.265	12.000	6.000	8.000
2	371	45.000	0.675	0.455	0.225	11.500	5.000	8.000
2	372	48.000	0.730	0.475	0.250	13.000	6.000	8.000
2	373	47.500	0.835	0.545	0.260	12.500	6.000	8.000
2	374	44.500	0.720	0.440	0.225	11.500	5.000	8.000
2	375	45.500	0.620	0.435	0.200	11.000	5.000	7.000
2	376	48.500	0.840	0.555	0.280	12.500	5.500	8.500
2	377	52.000	1.105	0.620	0.320	13.000	5.000	9.500
2	378	54.000	1.300	0.775	0.400	14.500	7.500	9.500
2	379	48.500	0.770	0.515	0.245	12.000	5.500	7.500
2	380	49.000	0.865	0.570	0.285	13.000	6.000	8.500
2	381	52.000	0.875	0.575	0.285	13.000	6.000	8.000
2	382	50.000	0.840	0.595	0.265	12.500	6.000	8.000
2	383	34.000	1.150	0.770	0.350	14.000	6.000	9.000
2	384	50.000	0.985	0.660	0.310	14.000	6.000	9.000
2	385	51.000	1.035	0.620	0.305	13.000	5.500	9.000
2	386	42.000	0.700	0.465	0.220	11.000	5.500	7.500
2	387	47.500	0.865	0.550	0.275	12.000	5.000	8.000
2	388	47.000	0.705	0.470	0.245	13.000	6.000	7.500
2	389	45.000	0.645	0.435	0.230	12.000	5.000	8.000
3	390	63.500	1.760	1.100	0.645	17.500	8.500	11.000
3	391	70.000	2.280	1.435	0.835	19.000	9.500	12.000
3	392	66.500	1.820	1.155	0.650	17.500	8.500	11.000
3	393	55.500	1.145	0.745	0.390	13.500	7.000	9.000
3	394	63.000	1.810	1.140	0.630	17.500	7.500	11.500
3	395	55.500	1.340	0.840	0.440	14.500	7.500	10.000
3	396	61.000	1.430	0.915	0.500	15.000	8.000	9.500
3	397	70.000	2.175	1.390	0.785	19.000	8.500	11.500
3	398	66.500	2.015	1.250	0.710	16.500	8.500	10.500
3	399	55.500	1.060	0.700	0.365	15.000	6.000	9.000
3	400	69.000	3.250	1.690	1.110	20.500	9.500	13.000
3	401	66.000	2.250	1.185	0.775	20.000	9.000	11.000
3	402	63.000	2.500	1.285	0.720	16.500	8.000	11.000
3	403	68.000	3.250	1.555	1.085	20.000	9.500	12.000
3	404	60.000	1.700	1.085	0.585	16.000	8.000	10.000
3	405	64.000	2.000	1.185	0.645	16.500	7.500	10.000
3	406	58.500	1.675	1.000	0.535	16.500	7.500	9.500
3	407	62.500	1.565	1.015	0.535	17.500	8.000	10.000
3	408	58.500	1.355	0.885	0.445	15.000	7.000	9.500
3	409	58.500	1.365	0.875	0.435	15.000	7.000	10.000
3	410	60.500	1.775	1.145	0.605	16.500	6.500	10.500
3	411	62.000	2.185	1.225	0.775	19.000	8.500	11.500
3	412	62.000	2.385	1.220	0.780	18.000	8.000	11.000
3	413	64.500	2.135	1.355	0.725	17.000	8.500	11.000
3	414	58.000	1.605	0.935	0.630	16.500	8.000	10.000
3	415	56.500	1.515	0.910	0.535	16.000	7.000	9.500
3	416	61.000	1.905	1.125	0.690	16.500	8.500	10.500
3	417	61.500	1.745	1.115	0.630	16.000	7.500	11.500
3	418	58.000	1.765	1.025	0.670	16.000	8.000	10.500

Table 3. (continued)

3	419	57.500	1.665	1.000	0.545	15.500	7.500	11.000
3	420	61.500	1.580	1.010	0.555	16.000	7.500	11.500
3	421	61.500	1.835	1.230	0.535	15.500	7.000	11.000
3	422	66.500	2.110	1.350	0.735	17.500	7.500	12.000
3	423	63.500	1.765	1.150	0.625	17.000	8.000	11.500
3	424	60.500	1.370	0.880	0.490	15.000	6.500	10.500
3	425	60.500	1.420	0.925	0.500	16.000	7.500	9.500
3	426	57.500	1.445	0.895	0.460	14.000	6.500	9.500
3	427	56.500	1.260	0.845	0.420	14.500	6.500	8.500
3	428	56.500	1.305	0.885	0.435	14.500	6.500	10.000
3	429	59.000	1.405	0.935	0.465	15.500	6.500	10.000
3	430	57.500	1.500	0.940	0.465	15.000	8.000	9.000
3	431	67.000	2.015	1.330	0.665	18.500	8.500	10.000
3	432	60.000	1.415	0.945	0.455	14.500	7.000	9.500
3	433	60.000	1.470	0.950	0.515	16.000	7.500	11.000
3	434	58.500	1.435	0.935	0.480	16.500	7.500	9.500
3	435	59.000	1.645	1.000	0.535	15.000	7.500	10.000
3	436	62.000	1.500	0.965	0.530	16.000	8.000	9.500
3	437	56.000	1.140	0.750	0.395	14.000	6.500	9.500
3	438	60.500	1.430	0.930	0.515	15.500	7.000	9.500
3	439	58.500	1.335	0.880	0.510	15.500	8.000	9.500
3	440	60.500	1.415	0.945	0.470	16.000	7.500	10.000
3	441	61.500	1.570	0.950	0.490	16.000	7.500	10.500
3	442	62.000	1.760	1.015	0.545	17.000	8.000	10.500
3	443	61.500	1.685	1.115	0.570	16.000	8.000	11.000
3	444	66.500	2.170	1.380	0.700	17.500	8.500	11.000
3	445	56.000	1.310	0.855	0.420	14.500	7.000	10.000
3	446	61.500	1.990	1.235	0.545	16.000	8.000	10.000
3	447	64.000	2.170	1.340	0.700	17.000	8.000	11.500
3	448	61.500	1.815	1.145	0.630	17.500	8.000	11.000
3	449	58.500	1.365	0.910	0.455	15.000	6.000	9.500
3	450	60.000	1.475	0.880	0.515	15.500	7.000	9.500
3	451	58.000	1.495	0.915	0.460	15.000	7.500	9.500
3	452	62.000	1.850	1.155	0.500	16.000	7.500	10.000
3	453	63.500	1.675	1.120	0.600	17.000	7.500	10.000
3	454	66.000	2.035	1.210	0.695	16.500	8.500	11.500
3	455	61.000	1.805	1.035	0.570	16.000	7.000	10.500
3	456	64.000	1.810	1.185	0.605	16.500	7.500	10.000
3	457	62.000	1.755	1.175	0.585	16.000	7.500	10.000
3	458	59.500	1.565	0.900	0.540	15.500	7.000	10.000
3	459	62.500	1.940	1.180	0.600	16.500	7.500	10.500
3	460	62.000	1.560	1.000	0.535	16.000	7.000	10.000
3	461	55.000	1.225	0.785	0.400	13.500	6.500	9.000
3	462	59.500	1.550	1.000	0.450	15.000	6.500	10.000
3	463	57.500	1.315	0.840	0.480	15.000	6.500	10.000
3	464	69.500	2.280	1.430	0.800	17.000	8.000	11.000
3	465	63.000	1.715	1.000	0.590	16.000	7.500	10.500
3	466	61.500	1.830	1.120	0.585	16.000	7.500	11.000
3	467	66.000	2.075	1.250	0.645	16.500	7.500	11.000
3	468	65.000	2.010	1.285	0.710	17.000	8.000	10.500
3	469	59.500	1.510	0.935	0.425	15.000	6.500	9.500
3	470	63.000	1.765	1.130	0.515	15.000	7.500	9.500
3	471	61.500	1.580	1.075	0.520	15.500	7.500	11.000
3	472	59.500	1.705	1.040	0.510	14.500	7.000	11.000
3	473	60.000	1.635	0.900	0.530	15.500	7.000	10.000

Table 3. (continued)

3	474	62.000	1.920	1.185	0.565	15.500	8.000	11.000
3	475	61.000	1.790	1.020	0.485	15.500	7.500	11.000
3	476	64.000	1.920	1.180	0.605	17.000	8.000	11.500
3	477	57.500	1.410	0.915	0.455	14.500	7.000	9.500
3	478	59.000	1.600	0.940	0.485	14.500	7.000	10.000
3	479	57.500	1.730	1.045	0.550	16.000	7.500	10.000
3	480	59.500	1.585	1.000	0.560	15.500	7.500	10.500
3	481	60.500	1.640	0.965	0.515	16.500	7.000	10.500
3	482	59.500	1.685	1.050	0.515	15.000	7.500	10.500
3	483	57.000	1.505	0.940	0.440	13.500	7.500	10.500
3	484	58.000	1.500	0.930	0.460	14.500	6.500	10.000
3	485	61.500	1.890	1.215	0.530	16.000	7.500	10.000
3	486	62.000	1.745	1.070	0.550	15.500	7.000	10.500
3	487	57.500	1.550	0.925	0.505	15.500	7.000	10.500
3	488	58.000	1.585	0.850	0.500	16.000	7.000	11.000
3	489	58.500	1.630	1.000	0.440	14.500	7.000	10.000
3	490	60.500	1.710	1.085	0.485	15.500	7.500	10.500
3	491	57.500	1.600	0.870	0.510	15.000	7.000	10.500
3	492	56.000	1.365	0.855	0.390	14.000	7.000	9.000
4	493	72.000	3.500	1.935	1.095	20.000	11.000	10.000
4	494	75.500	3.500	1.980	1.160	22.500	10.500	13.000
4	495	77.500	4.500	2.175	1.060	20.500	11.000	13.000
4	496	73.500	3.500	1.800	0.965	20.000	10.000	13.000
4	497	70.000	3.250	1.515	0.945	20.000	9.000	12.000
4	498	71.000	3.000	1.375	0.870	19.500	9.000	11.500
4	499	84.000	5.750	4.000	1.310	22.500	10.500	12.000
4	500	73.500	3.500	1.900	1.040	19.500	10.500	13.000
4	501	85.000	5.000	2.545	1.520	24.000	10.500	13.500
4	502	72.000	4.250	2.065	1.185	21.000	11.000	12.500
4	503	71.000	4.000	1.725	1.065	20.000	9.500	12.000
4	504	84.500	5.250	2.605	1.830	22.500	12.500	15.000
4	505	79.500	3.750	2.015	1.340	22.500	11.500	12.000
4	506	88.500	7.250	4.250	1.985	25.500	11.000	16.000
4	507	75.000	4.250	2.095	1.215	21.500	10.500	13.000
4	508	75.000	3.500	1.945	0.895	17.500	10.000	12.500
4	509	77.000	3.500	2.080	1.095	21.500	10.500	12.500
4	510	85.000	5.750	3.500	1.575	22.500	10.500	15.500
4	511	73.000	3.250	1.685	0.975	20.500	10.000	12.000
4	512	81.500	5.250	2.750	1.640	23.500	10.500	14.500
4	513	81.000	5.200	3.000	1.690	22.500	12.000	15.000
4	514	78.500	4.750	2.750	1.685	23.500	10.000	13.500
4	515	80.500	4.250	3.000	1.495	23.000	10.000	13.000
4	516	82.500	5.150	3.500	1.575	23.000	11.000	13.000
4	517	80.000	5.000	2.500	1.510	23.000	9.500	13.500
4	518	71.500	3.500	2.250	0.940	20.000	8.500	11.500
4	519	79.500	4.650	2.400	1.455	21.500	10.000	13.500
4	520	75.000	4.250	1.960	1.300	20.500	9.500	12.500
4	521	77.500	5.250	1.955	1.575	24.000	10.500	15.000
4	522	75.500	3.500	1.990	1.135	23.500	9.000	12.000
4	523	80.000	4.500	3.000	1.380	22.500	10.000	12.500
4	524	80.500	4.000	2.250	1.370	23.000	11.000	12.000
4	525	74.500	4.250	2.500	1.270	21.000	10.000	13.500
4	526	78.000	4.500	2.750	1.625	23.500	10.500	12.500
4	527	75.000	3.750	2.250	1.180	23.000	10.000	12.000
4	528	74.000	4.000	2.250	1.215	21.000	10.000	12.500

Table 3. (continued)

4	529	81.000	4.500	2.465	1.370	22.500	11.500	12.500
4	530	76.000	4.000	1.970	1.360	21.500	11.500	12.500
4	531	75.000	4.250	1.965	1.050	21.000	10.000	13.500
4	532	87.500	5.750	3.250	1.675	23.500	10.500	13.500
4	533	85.000	4.500	2.650	1.555	23.000	11.500	13.000
4	534	78.000	4.000	2.350	1.290	23.500	10.500	11.500
4	535	85.500	5.350	3.650	1.625	23.500	11.000	13.500
4	536	74.000	2.545	1.550	0.880	19.000	9.000	12.500
4	537	74.000	3.500	1.755	0.910	18.500	8.500	13.000
4	538	78.000	3.150	1.845	1.175	22.500	10.000	12.500
4	539	85.500	3.750	2.125	1.350	22.500	10.000	13.000
4	540	77.000	3.750	2.055	1.225	21.500	10.000	12.000
4	541	84.500	5.250	3.250	1.745	23.000	11.500	15.000
4	542	93.000	6.750	3.750	2.010	26.500	11.500	16.000
4	543	74.000	3.250	1.955	1.060	21.000	10.500	12.000
4	544	72.000	3.250	1.700	1.025	21.500	9.500	12.500
4	545	77.500	3.750	2.180	1.105	21.500	9.500	11.500
4	546	89.500	5.650	3.000	1.800	24.000	11.500	15.000
4	547	89.000	6.000	3.500	2.140	25.000	13.000	16.000
4	548	78.500	4.250	3.000	1.515	22.500	11.500	12.000
4	549	76.500	4.250	2.100	1.315	22.500	10.500	11.500
4	550	81.500	3.950	2.750	1.460	23.000	12.000	14.500
4	551	83.500	4.750	3.250	1.735	24.000	11.000	13.500
4	552	79.000	4.750	2.060	1.425	21.500	10.500	13.000
4	553	84.500	4.850	3.250	1.790	24.500	11.000	13.000
4	554	90.500	7.000	4.250	2.315	26.500	11.000	15.500
4	555	90.000	5.250	3.500	2.030	25.000	12.000	16.000
4	556	81.500	4.250	2.750	1.395	22.000	10.500	13.000
4	557	81.000	5.750	2.750	1.745	22.500	10.000	14.000
4	558	79.000	3.650	2.350	1.250	21.000	9.500	13.000
4	559	91.500	5.500	3.250	2.100	26.500	11.500	15.500
4	560	84.500	4.215	2.650	1.530	23.500	10.000	14.500
4	561	74.500	3.500	2.350	1.190	21.500	9.500	11.500
4	562	75.000	3.750	2.350	1.295	24.500	11.000	13.000
4	563	72.000	3.250	2.150	1.150	22.000	10.500	12.500
4	564	88.000	4.250	2.750	1.635	25.000	9.500	14.000
4	565	85.500	5.750	3.250	1.950	23.500	10.500	15.000
4	566	73.500	3.250	1.885	1.130	21.500	9.500	12.500
4	567	74.500	2.750	1.600	1.090	21.000	9.000	12.500
4	568	72.000	3.150	1.785	1.135	21.500	9.000	11.500
4	569	82.000	4.250	2.485	1.600	23.500	10.500	13.500
4	570	75.000	3.500	2.070	1.245	22.500	10.000	13.500
4	571	79.500	4.350	2.265	1.325	22.000	9.500	13.000
4	572	79.000	3.650	1.885	1.300	24.500	10.500	12.000

Table 4. The means square error (MSE), pearson's correlation coefficient (r) and both the a_0 and a_1 coefficient values for each of the six morphological parameters per boat trip.

Statistical analysis	Boat trip	Dependant morphological parameter					
		Whole hake mass (kg)	H & G hake mass (kg)	Hake head mass (kg)	Hake head length (cm)	Hake head breadth (cm)	Hake head height (cm)
MSE	1	0.025	0.005	0.003	0.344	0.110	0.626
	2	0.117	0.021	0.008	0.907	0.398	0.533
	3	0.108	0.040	0.008	0.778	0.405	0.560
r	1	0.98	0.98	0.92	0.95	0.95	0.97
	2	0.99	0.99	0.99	0.99	0.97	0.98
	3	0.98	0.97	0.98	0.98	0.96	0.97
a_0 coefficient value	1	-2.848452	-3.554887	-4.579208	1.629598	0.569145	0.977130
	2	-2.162518	-2.397204	-3.305177	1.630344	0.943680	1.167778
	3	-2.471027	-2.907605	-3.585683	1.567198	0.813176	1.137197
a_1 coefficient value	1	0.051104	0.053117	0.058231	0.018493	0.021753	0.021811
	2	0.045476	0.039880	0.045474	0.018996	0.017784	0.018194
	3	0.048746	0.047539	0.048746	0.019468	0.019382	0.018482

Appendix 4:

Table 1. Average moisture, protein, fat and ash content for each of the nine hake head sections in category number two sampled during boat trip 1.

Category number	Batch number	Hake head section	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
2	1	Neck flesh	82.650	16.171	1.091	2.375
2	2	Neck flesh	82.849	14.923	1.254	2.001
2	3	Neck flesh	82.357	15.311	1.405	2.236
2	4	Neck flesh	83.626	15.598	1.397	2.456
2	1	Clean head	85.464	14.043	1.344	4.805
2	2	Clean head	84.892	12.582	1.020	4.569
2	3	Clean head	82.448	13.231	1.654	4.978
2	4	Clean head	84.066	13.178	1.646	4.220
2	1	Jaw	76.565	12.704	1.249	9.233
2	2	Jaw	78.958	12.823	1.533	8.237
2	3	Jaw	77.261	12.949	1.490	9.045
2	4	Jaw	78.497	12.743	1.509	9.730
2	1	Gills	84.627	11.998	2.333	3.557
2	2	Gills	83.293	11.241	2.541	3.479
2	3	Gills	84.059	12.483	2.104	3.556
2	4	Gills	84.715	11.790	2.046	3.795
2	1	Gut & gall	83.025	11.841	4.941	1.474
2	2	Gut & gall	81.526	12.106	5.903	1.466
2	3	Gut & gall	80.998	11.515	6.384	1.447
2	4	Gut & gall	83.081	11.649	5.529	1.386
2	1	Kidney & kidney bone	78.798	13.170	2.753	5.320
2	2	Kidney & kidney bone	82.556	13.004	3.216	4.873
2	3	Kidney & kidney bone	80.168	13.190	3.144	5.292
2	4	Kidney & kidney bone	81.962	12.470	3.331	5.506
2	1	Tongue	86.460	16.430	1.089	0.752
2	1	Tongue cartilage	85.532	12.908	1.071	4.840
2	1	Gill cover	87.883	10.830	1.514	3.646

Table 2. Macro and trace elements present in category 2 head sections sampled during boat trip 1.

Category number	Hake head section	Macro elements					Trace elements			
		P (mg.kg^{-1})	K (mg.kg^{-1})	Ca (mg.kg^{-1})	Mg (mg.kg^{-1})	Na (mg.kg^{-1})	Cu (µg.kg^{-1})	Zn (µg.kg^{-1})	Pb (µg.kg^{-1})	Fe (µg.kg^{-1})
2	Neck flesh	295.4338	41.0204	521.3435	21.4743	39.0853	-178.2390	851.9525	530.2689	2218.9063
2	Clean head	400.7717	21.6482	782.8097	15.3246	42.1974	-239.9080	1262.9433	437.5041	530.8555
2	Jaw	811.1593	19.0841	1554.3046	25.6868	56.1836	-264.2419	922.0396	528.3129	1555.7846
2	Tongue	40.4947	28.1665	19.4433	10.1269	33.6622	-172.7985	1583.4906	913.9528	458.1009
2	Tongue cartilage	627.1876	23.7589	1022.3148	22.4874	55.2070	-271.1414	1326.3124	279.6241	827.2941
2	Gills	512.2369	30.2889	897.8554	24.1500	46.7818	-234.5339	1797.6041	878.8536	2869.4096
2	Gill cover	472.2709	29.4002	845.4326	21.7933	39.6467	-200.8548	2391.1672	472.4447	1948.3423
2	Kidney & k. bone	736.6777	46.1933	1314.6357	25.4817	51.5873	-214.1321	1426.9702	594.9561	1856.2955
2	Gut & gall	146.8242	28.5470	177.7364	18.9076	27.3122	-153.0984	1942.7422	696.0984	3512.2778

Table 3. Average moisture, protein, fat and ash content for each hake head section per category sampled on the second boat trip.

Category number	Batch number	Hake head section	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
1	1	Neck flesh	88.739	14.837	1.220	1.215
1	1	Clean head	84.410	13.632	1.370	3.132
1	1	Jaw	74.371			10.008
1	1	Tongue	81.490	21.900	1.039	0.742
1	1	Tongue cartilage	80.032	15.882	0.859	5.282
1	1	Heart	86.029	14.372	2.419	0.953
1	1	Gills	85.646	13.648	1.015	3.372
1	1	Gut	85.770	14.921	1.334	0.570
1	1	Kidney	85.823	14.310	2.909	1.192
1	1	Intestines	86.294	9.524	4.682	0.790
2	1	Neck flesh	83.770	18.736	0.958	1.3561
2	2	Neck flesh	83.949	19.410	0.943	1.4819
2	3	Neck flesh	83.403	18.887	1.047	2.0768
2	4	Neck flesh	84.537	18.115	1.091	1.5816
2	1	Clean head	80.938	18.698	1.000	4.0359
2	2	Clean head	82.726	15.638	1.210	3.4619
2	3	Clean head	82.984	15.560	1.191	4.5762
2	4	Clean head	84.828	14.572	1.024	3.5854
2	1	Jaw	80.269	15.340	0.792	7.2938
2	2	Jaw	79.018	15.730	0.818	6.9958
2	1	Tongue	85.610	16.360	1.278	0.4971
2	1	Tongue cartilage	84.403	13.592	1.050	4.4361
2	1	Heart	84.915	13.742	2.100	0.9334
2	1	Gills	84.870	12.132	1.264	3.2223
2	2	Gills	84.694	13.381	1.518	3.0092
2	1	Gut	89.070	11.419	1.616	0.6096
2	1	Kidney	85.408	14.382	2.984	0.9906
2	1	Intestines	87.954	7.502	4.665	0.6208
3	1	Neck flesh	83.026	19.699	1.127	1.7234
3	2	Neck flesh	82.581	18.405	1.036	1.6704
3	3	Neck flesh	82.964	20.707	1.148	2.0229
3	4	Neck flesh	83.425	17.395	1.095	2.0593
3	1	Clean head	83.013	15.914	1.138	4.5962
3	2	Clean head	83.565	17.990	1.307	4.3562
3	3	Clean head	83.453	15.951	1.249	4.2814
3	4	Clean head	81.221	17.969	0.889	4.9972
3	1	Jaw	77.502	19.004	0.605	9.1662
3	2	Jaw	77.298	18.261	0.692	8.2092
3	3	Jaw	74.004	18.095	0.677	7.7048

Table 3. continued

3	4	Jaw	76.960	19.546	0.667	8.1001
3	1	Tongue	82.123	20.489	0.914	0.5742
3	2	Tongue	83.621	19.874	0.942	0.5403
3	1	Tongue cartilage	82.697	14.149	0.691	3.3976
3	2	Tongue cartilage	82.541	15.572	0.761	3.7359
3	1	Heart	85.582	14.129	2.734	0.9262
3	1	Gills	80.655	18.519	1.003	2.3400
3	2	Gills	82.263	14.182	0.956	1.7516
3	3	Gills	81.659	15.645	1.453	2.8308
3	4	Gills	79.776	17.737	1.199	2.8416
3	1	Gut	85.910	14.722	1.389	0.5795
3	2	Gut	85.732	14.221	1.387	0.5598
3	3	Gut	86.552	14.266	1.515	0.6008
3	4	Gut	84.851	14.528	1.152	0.6417
3	1	Kidney	84.676	11.871	2.463	1.0889
3	1	Intestines	83.041	11.458	5.060	0.9207
4	1	Neck flesh	78.969	18.221	0.803	2.9947
4	2	Neck flesh	78.269	18.793	0.998	2.5803
4	3	Neck flesh	80.374	19.298	1.144	2.4378
4	4	Neck flesh	79.495	17.642	1.004	2.8960
4	1	Clean head	74.756	18.894	1.115	5.1902
4	2	Clean head	80.725	15.764	1.055	5.3968
4	3	Clean head	81.287	14.970	0.908	5.3489
4	4	Clean head	81.186	15.561	0.921	4.2977
4	1	Jaw	69.329	18.688	0.781	12.7141
4	1	Tongue	78.208	21.188	1.222	0.9556
4	2	Tongue	79.741	21.629	1.148	0.8222
4	3	Tongue	78.997	21.124	1.190	0.9245
4	4	Tongue	79.269	22.852	1.225	0.9341
4	1	Tongue cartilage	77.102	18.311	0.988	5.2684
4	2	Tongue cartilage	75.426	16.646	0.837	6.0261
4	3	Tongue cartilage	77.128	17.187	0.823	5.8745
4	4	Tongue cartilage	74.673	16.611	0.811	4.0906
4	1	Heart	85.709	11.418	1.299	1.0811
4	1	Gills	75.863	17.583	1.149	4.7709
4	2	Gills	82.055	15.671	1.243	3.5755
4	3	Gills	79.950	16.516	1.156	3.8902
4	4	Gills	80.841	16.139	2.897	4.3562
4	1	Gut	85.313	15.255	1.438	0.8437
4	2	Gut	84.991	14.221	1.208	0.8851
4	3	Gut	85.235	14.736	1.152	0.8332
4	4	Gut	84.821	15.891	0.952	0.8088
4	1	Kidney	84.739	14.339	2.343	1.2401
4	2	Kidney	84.904	14.383	2.620	1.3553
4	3	Kidney	84.489	14.867	2.565	1.2897
4	4	Kidney	84.451	14.323	2.515	1.2717
4	1	Intestines	85.532	10.087	6.270	0.7855

Table 4. Macro and trace elements present in each hake head section per category sampled during the second boat trip.

		Macro elements					Trace elements			
Category number	Hake head section	P (mg.kg^{-1})	K (mg.kg^{-1})	Ca (mg.kg^{-1})	Mg (mg.kg^{-1})	Na (mg.kg^{-1})	Cu (µg.kg^{-1})	Zn (µg.kg^{-1})	Pb (µg.kg^{-1})	Fe (µg.kg^{-1})
1	Neck flesh	973.9856	<401.0000	2299.4092	100.4109	658695.3895	435.7832	7149.2548	13.6930	9006.8562
1	Clean head	5474.7262	<568.0000	14362.2688	255.9612	1978011.4762	348.3917	17775.0852	9.7329	12911.8219
1	Jaw	13970.0576	<976.0000	34925.1440	586.1563	4437691.3800	249.1164	26377.0319	12.3508	18830.2700
1	Tongue	524.1176	<698.0000	209.6471	104.8235	1726094.1043	627.1941	19916.4704	12.1281	5905.0588
1	Tongue cartilage	8178.6432	<764.0000	18936.9986	324.8526	5446059.1281	498.7444	15745.7990	9.8621	10376.1758
1	Heart	866.4058	<462.0000	184.8332	115.5208	1353903.4287	1917.6448	13400.4094	9.0331	20331.6556
1	Gills	5722.2997	<533.0000	12258.2598	253.4352	1956786.4115	316.1270	22409.0059	7.3610	8990.2798
1	Gut	541.6347	<515.0000	154.7528	64.4803	1495943.5642	60.6115	11593.5626	8.3154	5197.1143
1	Kidney	1408.4819	878.8927	157.7500	191.5535	1779194.3545	64.2268	21296.2465	8.2689	39550.1722
1	Intestine	2265.0068	803.1299	1055.8000	469.2444	1978948.1689	114.6039	31944.7174	9.1913	39344.3412
2	Neck flesh	2562.8393	<603.0000	4251.2981	195.9818	1619111.3850	310.5558	9196.0703	9.8873	6226.1918
2	Clean head	6858.7107	<641.0000	17226.9019	304.4755	3772290.8850	366.9731	19710.7808	7.8851	11297.6426
2	Jaw	10049.5738	<782.0000	24165.9012	391.0340	4062843.2600	289.3652	19747.2170	9.5696	22288.9380
2	Tongue	498.2528	<524.0000	432.6932	78.6715	1461978.6654	548.0781	15865.4187	9.4176	5218.5427
2	Tongue cartilage	7288.0665	<581.0000	15856.2723	276.3937	3326907.7844	472.7788	16874.5651	6.9688	7928.1362
2	Heart	1129.6902	610.2924	610.2924	181.7892	1769847.9655	1830.8772	19607.2665	14.4918	24671.3950
2	Gills	4742.6439	<553.0000	9803.3076	235.0582	2072659.8050	1054.9963	21431.7725	7.1451	15900.9925
2	Gut	493.6311	<372.0000	279.4138	102.4517	742309.3611	60.5397	16951.1046	8.2213	10524.5869
2	Kidney	1172.3403	708.0471	336.6126	185.7173	1997621.5079	44.1079	24027.1733	8.1710	48402.5665
2	Intestine	1468.8848	524.0745	553.5998	376.4479	1388428.3164	7204.1788	27901.4303	30.1018	29377.6964
3	Neck flesh	3370.7417	635.9890	6455.2884	222.5962	1969975.9275	748.8770	10000.9270	16.0500	5882.8983
3	Clean head	6705.1798	<641.0000	16522.3330	272.6987	3870717.4300	879.0523	14709.6887	8.8314	9640.7011
3	Jaw	12296.5751	<915.0000	28783.6031	457.9730	5296457.7450	1085.3960	16807.6091	11.0143	12708.7508
3	Tongue	2017.2609	<2305.0000	1037.4485	345.8162	6259272.3150	28068.7442	115848.4103	99.3904	26800.7516
3	Tongue cartilage	22896.0368	<2318.0000	49791.6344	985.3991	14769392.8200	3188.0558	50545.1748	33.0051	28808.4311
3	Heart	432.3294	<467.0000	198.6378	151.8995	1377611.7023	1986.3782	17994.2495	13.6482	21967.0059

Table 4. continued

3	Gills	728.1139	<710.0000	9447.7215	213.1065	2198548.7250	1335.4674	25395.1913	11.7280	14402.4476
3	Gut	296.2009	<515.0000	115.9047	77.2698	1260785.5700	55.3767	9542.8203	11.3342	3760.4636
3	Kidney	604.4869	<514.0000	141.4757	180.0599	1764587.3510	61.7348	24693.9338	11.0936	45272.2119
3	Intestine	1903.8829	<475.0000	1106.6320	475.9707	2538113.9290	1511.2071	41528.4464	8.7787	47954.0513
4	Neck flesh	927.5744	<789.0000	9137.5944	296.0344	2948502.3750	536.8090	12038.7313	12.6870	6631.1700
4	Clean head	975.5813	<780.0000	19257.9739	331.6976	5736417.7500	798.0255	16936.0905	10.6153	8233.9058
4	Jaw	19009.8620	<1195.0000	44834.5802	627.6841	9229945.5809	777.1327	18471.8470	13.3278	11627.1011
4	Tongue	474.0084	<790.0000	296.2553	118.5021	2150813.1150	803.8392	23502.9165	14.9303	7919.8904
4	Tongue cartilage	9866.6840	<922.0000	21715.9260	368.8480	6535525.5000	1002.8055	18534.6120	16.3331	12586.9380
4	Heart	597.6092	1299.1504	246.8386	207.8641	1553783.9063	2221.5472	17798.3608	12.3965	22605.2174
4	Gills	6492.9339	2076.9904	13154.2724	261.9628	3822784.9875	879.4464	26383.3913	10.0098	15118.9930
4	Gut	494.0019	<548.0000	192.1119	109.7782	1936213.0025	42.5391	15368.9480	9.1157	7698.1963
4	Kidney	2067.7955	<513.0000	205.4952	231.1821	2496766.6800	93.7572	25815.3345	9.1914	61776.9945
4	Intestine	2230.0053	<327.0000	910.0389	426.3245	1914361.1510	2402.1748	23037.9222	11.2763	35417.7309

Table 5. Average moisture, protein, fat and ash percentage for each hake head section per category sampled on the third boat trip.

Category number	Batch number	Hake head section	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
1	1	Neck flesh	82.251	14.050	0.711	3.499
1	2	Neck flesh	84.446	12.212	0.649	2.974
1	3	Neck flesh	84.274	12.471	0.645	3.273
1	4	Neck flesh	82.859	13.717	0.638	3.019
1	1	Clean head	82.222	12.906	0.843	4.117
1	2	Clean head	82.282	12.878	1.005	3.884
1	3	Clean head	78.728	15.894	1.039	4.574
1	4	Clean head	82.657	12.562	0.941	4.273
1	1	Tongue	84.137	16.036	0.551	0.887
1	1	Tongue cartilage	79.888	11.855	0.399	7.477
1	1	Gills	83.594	10.900	0.679	4.597
1	2	Gills	83.021	11.216	0.901	4.641
1	3	Gills	84.035	10.896	0.792	4.185
1	4	Gills	84.437	10.735	0.758	3.921
1	1	Gut	86.224	10.921	1.581	0.826
1	2	Gut	84.103	12.495	1.843	0.892
1	1	Kidney	86.697	10.516	1.368	1.090
1	1	Heart	86.411	11.648	1.042	0.873
1	1	Intestine	83.539	11.436	2.739	2.026
1	1	Jaw	75.599	13.205	0.944	10.957
1	2	Jaw	77.153	12.008	0.797	10.027
1	3	Jaw	77.912	12.237	0.554	10.119
1	4	Jaw	77.642	12.132	1.010	9.600
2	1	Neck flesh	81.532	14.563	0.877	4.123
2	2	Neck flesh	77.125	17.955	0.971	3.633
2	3	Neck flesh	79.440	16.442	0.974	3.791
2	4	Neck flesh	77.607	17.658	0.938	4.437
2	1	Clean head	77.190	16.102	0.924	5.812
2	2	Clean head	78.957	15.087	0.909	5.845
2	3	Clean head	78.309	15.286	0.896	5.833
2	4	Clean head	82.698	11.914	0.778	4.980
2	1	Tongue	83.375	16.926	0.938	0.872
2	2	Tongue	84.335	15.764	0.872	0.771
2	3	Tongue	83.430	16.555	0.682	0.839
2	1	Tongue cartilage	80.837	12.229	0.303	5.676
2	2	Tongue cartilage	81.081	12.038	0.300	6.704
2	3	Tongue cartilage	81.047	11.904	0.547	6.200
2	1	Gills	80.664	13.491	1.061	5.619
2	2	Gills	81.285	12.742	0.985	5.265
2	3	Gills	80.554	13.186	0.840	4.695
2	4	Gills	83.764	11.294	0.631	4.163
2	1	Kidney	85.243	11.503	1.500	2.844
2	2	Kidney	85.450	11.186	1.720	1.238
2	3	Kidney	86.012	10.778	1.483	1.110

Table 5. continued

2	1	Gut	85.565	11.854	1.426	0.802
2	2	Gut	83.281	13.854	1.705	0.786
2	3	Gut	85.850	11.579	1.451	0.855
2	4	Gut	85.229	11.981	1.533	0.758
2	1	Heart	82.990	14.831	1.224	0.959
2	1	Intestine	84.016	11.074	2.649	1.816
2	2	Intestine	82.175	12.312	3.158	1.633
2	3	Intestine	83.043	11.514	3.084	1.605
2	1	Jaw	70.472	16.440	0.574	11.153
2	2	Jaw	70.359	16.590	0.598	10.158
2	3	Jaw	72.509	15.781	0.619	9.461
2	4	Jaw	72.344	15.350	0.519	10.666
3	1	Neck flesh	73.920	20.630	1.129	5.721
3	2	Neck flesh	75.896	18.820	1.103	4.535
3	3	Neck flesh	75.661	19.243	1.238	4.795
3	4	Neck flesh	75.784	19.635	1.108	4.019
3	1	Clean head	79.626	14.640	0.950	4.914
3	2	Clean head	75.545	17.306	1.148	6.247
3	3	Clean head	79.602	14.325	0.960	6.076
3	4	Clean head	78.720	14.966	0.794	5.592
3	1	Tongue	80.266	19.948	0.824	0.859
3	2	Tongue	81.271	18.658	0.827	0.772
3	3	Tongue	81.021	18.586	0.945	0.866
3	1	Tongue cartilage	83.699	10.574	0.382	6.506
3	2	Tongue cartilage	82.252	12.301	0.404	6.220
3	3	Tongue cartilage	79.647	14.149	0.553	6.009
3	4	Tongue cartilage	80.301	14.136	0.502	4.939
3	1	Gills	78.406	15.810	0.926	5.674
3	2	Gills	80.864	13.913	0.805	6.519
3	3	Gills	78.602	15.272	0.850	6.583
3	4	Gills	76.844	16.953	0.879	6.982
3	1	Gut	83.868	14.337	1.412	0.835
3	2	Gut	81.072	16.853	1.834	0.851
3	3	Gut	86.498	11.931	1.256	0.726
3	4	Gut	85.511	12.655	1.146	0.642
3	1	Jaw	70.189	17.052	0.511	11.540
3	2	Jaw	67.581	18.371	0.551	11.769
3	3	Jaw	71.844	15.609	0.389	11.479
3	4	Jaw	67.835	17.807	0.510	11.239
3	1	Intestine	82.498	11.410	3.739	1.174
3	2	Intestine	83.996	10.693	3.253	1.045
3	3	Intestine	83.782	10.909	3.074	1.086
3	4	Intestine	83.029	10.619	4.341	1.022
3	1	Kidney	83.919	11.858	2.119	1.261
3	2	Kidney	83.849	12.210	2.039	1.280
3	3	Kidney	85.467	11.149	1.777	1.135
3	1	Heart	80.567	17.201	1.655	0.916
4	1	Neck flesh	73.372	21.793	1.032	3.894
4	2	Neck flesh	73.269	22.131	0.950	4.762

Table 5. continued

4	3	Neck flesh	74.375	21.185	0.920	4.772
4	4	Neck flesh	75.698	19.572	0.777	4.476
4	1	Clean head	67.482	23.715	1.121	6.445
4	2	Clean head	74.822	19.197	0.998	5.445
4	3	Clean head	69.495	21.935	1.115	6.986
4	4	Clean head	71.238	21.107	1.001	5.804
4	1	Tongue	80.036	19.832	0.794	0.885
4	2	Tongue	79.584	20.133	0.829	0.873
4	3	Tongue	79.251	20.660	0.824	0.911
4	4	Tongue	77.668	22.037	0.882	0.941
4	1	Tongue cartilage	75.706	16.498	0.483	7.308
4	2	Tongue cartilage	78.053	14.698	0.461	6.161
4	3	Tongue cartilage	75.550	16.430	0.429	6.854
4	4	Tongue cartilage	74.012	17.485	0.407	6.527
4	1	Gut	83.817	14.011	1.163	0.857
4	2	Gut	81.937	15.582	1.137	0.891
4	3	Gut	83.631	14.456	0.999	0.929
4	4	Gut	82.670	15.302	1.080	0.928
4	1	Gills	73.268	19.791	1.097	5.704
4	2	Gills	76.256	17.350	1.038	5.496
4	3	Gills	73.563	20.020	1.183	5.506
4	4	Gills	72.317	20.378	1.273	5.323
4	1	Kidney	82.456	13.118	2.134	1.309
4	2	Kidney	84.340	11.863	1.652	1.344
4	3	Kidney	84.710	11.229	1.709	1.261
4	4	Kidney	85.334	10.937	1.649	1.287
4	1	Intestine	83.094	10.861	4.430	1.239
4	2	Intestine	84.240	9.796	4.105	1.188
4	3	Intestine	83.420	10.477	4.222	1.186
4	4	Intestine	83.477	10.851	4.076	1.173
4	1	Heart	84.005	13.440	1.227	0.982
4	2	Heart	83.754	13.586	1.172	1.040
4	1	Jaw	68.771	19.970	0.437	14.079
4	2	Jaw	63.669	20.741	0.425	14.553
4	3	Jaw	66.438	19.053	0.469	14.678
4	4	Jaw	63.906	20.394	0.433	15.715

Table 6. The percentage moisture, protein, fat and ash present in both the clean head and neck flesh sections per category for each of the six days of the turnaround period.

Day	Category	Hake head section	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
1	1	Clean head	82.580	11.997	1.428	5.613
2	1	Clean head	81.943	12.544	1.318	6.015
3	1	Clean head	81.753	14.392	1.330	5.460
4	1	Clean head	81.558	13.954	1.268	6.000
5	1	Clean head	80.090	14.352	1.464	5.701
6	1	Clean head	80.476	14.233	1.701	6.092
1	2	Clean head	82.165	13.598	1.157	5.638
2	2	Clean head	80.954	13.622	1.095	6.418
3	2	Clean head	75.688	16.777	1.596	6.801
4	2	Clean head	79.791	14.600	1.152	6.138
5	2	Clean head	80.889	16.528	1.189	5.387
6	2	Clean head	81.656	17.045	1.584	5.680
1	3	Clean head	81.063	13.442	1.567	5.685
2	3	Clean head	81.340	14.218	0.885	6.113
3	3	Clean head	78.540	14.625	1.382	6.152
4	3	Clean head	81.449	13.551	1.291	5.573
5	3	Clean head	78.950	14.512	1.122	6.099
6	3	Clean head	82.349	11.938	1.253	5.408
1	4	Clean head	79.187	14.422	1.456	5.696
2	4	Clean head	78.847	16.721	1.207	5.463
3	4	Clean head	79.378	14.548	1.282	5.669
4	4	Clean head	74.890	19.426	1.128	6.636
5	4	Clean head	78.531	19.069	1.052	7.308
6	4	Clean head	81.994	14.454	1.290	5.094
1	1	Neck flesh	85.408	15.053	1.409	2.848
2	1	Neck flesh	81.538	16.861	1.499	3.542
3	1	Neck flesh	79.846	16.600	1.011	3.026
4	1	Neck flesh	83.020	14.691	0.999	3.217
5	1	Neck flesh	81.708	14.966	1.180	2.800
6	1	Neck flesh	82.911	16.469	1.229	3.707
1	2	Neck flesh	81.835	14.401	1.396	2.942
2	2	Neck flesh	82.632	16.249	0.964	3.252
3	2	Neck flesh	78.125	18.431	1.399	2.840
4	2	Neck flesh	79.562	19.090	1.127	3.410
5	2	Neck flesh	75.914	23.971	1.280	4.746
6	2	Neck flesh	81.028	17.191	1.277	3.617
1	3	Neck flesh	79.840	15.404	1.387	3.904

Table 6. continued

2	3	Neck flesh	81.191	18.531	1.241	4.190
3	3	Neck flesh	81.687	16.777	1.318	3.173
4	3	Neck flesh	80.900	16.906	0.754	2.983
5	3	Neck flesh	82.548	16.199	1.349	3.267
6	3	Neck flesh	82.041	16.923	1.124	3.330
1	4	Neck flesh	82.795	16.985	1.004	3.306
2	4	Neck flesh	82.083	20.052	1.234	4.051
3	4	Neck flesh	78.461	17.434	1.480	3.161
4	4	Neck flesh	80.795	16.680	1.295	2.984
5	4	Neck flesh	81.994	15.690	1.034	3.346
6	4	Neck flesh	83.256	18.515	1.258	2.891

Table 7. Macro and trace elements present in both the clean head and neck flesh sections per category sampled during the third boat trip.

		Macro elements					Trace elements			
Category number	Hake head section	P (mg.kg^{-1})	K (mg.kg^{-1})	Ca (mg.kg^{-1})	Mg (mg.kg^{-1})	Na (mg.kg^{-1})	Cu (µg.kg^{-1})	Zn (µg.kg^{-1})	Pb (µg.kg^{-1})	Fe (µg.kg^{-1})
1	Clean head	9449.9717	704.4524	21477.2083	377.9989	26.9754	510.2985	26975.3737	<171.8000	10034.1517
2	Clean head	9997.5780	740.5613	22216.8400	388.7947	27.0305	470.2564	27030.4887	<185.1000	6942.7625
3	Clean head	9611.4705	816.0683	21580.4715	362.6970	22.4872	641.9737	22487.2140	<181.3000	6836.8385
4	Clean head	10379.0093	918.1431	22354.7893	379.2330	23.3528	385.2209	23352.7710	<199.5000	6925.9928
1	Neck flesh	6058.1703	802.2982	10970.2003	311.0952	13.3116	609.0917	13311.6013	<163.7000	4600.9348
2	Neck flesh	6618.5817	945.5117	11913.4470	340.3842	15.4686	1389.9021	15468.5709	<189.1000	5578.5188
3	Neck flesh	6451.6283	1046.2100	11159.5733	313.8630	14.4726	739.3217	14472.5717	<174.3000	4812.5660
4	Neck flesh	6026.4342	1084.7581	10158.8462	292.7125	13.7575	442.5125	13757.4883	<172.1000	4872.8025

Table 8. The percentage Eicosapentaenoic acid present in both the clean head and neck flesh sections per category for each of the six days of sampling on the third boat trip.

Day sampled	Days on Trawler	Measurement	Category	Sample name	C20:5n-3(EPA)(%)
1	6	C20:5n-3(EPA)%	1	Clean head	4.5969
2	5	C20:5n-3(EPA)%	1	Clean head	3.8542
3	4	C20:5n-3(EPA)%	1	Clean head	0.0000
4	3	C20:5n-3(EPA)%	1	Clean head	0.0000
5	2	C20:5n-3(EPA)%	1	Clean head	2.9988
6	1	C20:5n-3(EPA)%	1	Clean head	0.0000
1	6	C20:5n-3(EPA)%	2	Clean head	7.0312
2	5	C20:5n-3(EPA)%	2	Clean head	7.3007
3	4	C20:5n-3(EPA)%	2	Clean head	0.0000
4	3	C20:5n-3(EPA)%	2	Clean head	0.2269
5	2	C20:5n-3(EPA)%	2	Clean head	0.0000
6	1	C20:5n-3(EPA)%	2	Clean head	0.0000
1	6	C20:5n-3(EPA)%	3	Clean head	5.3933
2	5	C20:5n-3(EPA)%	3	Clean head	4.4057
3	4	C20:5n-3(EPA)%	3	Clean head	0.0000

Table 8. continued

4	3	C20:5n-3(EPA)%	3	Clean head	0.0000
5	2	C20:5n-3(EPA)%	3	Clean head	4.6611
6	1	C20:5n-3(EPA)%	3	Clean head	0.0000
1	6	C20:5n-3(EPA)%	4	Clean head	0.0000
2	5	C20:5n-3(EPA)%	4	Clean head	0.0000
3	4	C20:5n-3(EPA)%	4	Clean head	1.3968
4	3	C20:5n-3(EPA)%	4	Clean head	0.0000
5	2	C20:5n-3(EPA)%	4	Clean head	3.6137
6	1	C20:5n-3(EPA)%	4	Clean head	0.0000
1	6	C20:5n-3(EPA)%	1	Neck flesh	0.1241
2	5	C20:5n-3(EPA)%	1	Neck flesh	0.0000
3	4	C20:5n-3(EPA)%	1	Neck flesh	3.0802
4	3	C20:5n-3(EPA)%	1	Neck flesh	3.1280
5	2	C20:5n-3(EPA)%	1	Neck flesh	2.2518
6	1	C20:5n-3(EPA)%	1	Neck flesh	5.9840
1	6	C20:5n-3(EPA)%	2	Neck flesh	4.2445
2	5	C20:5n-3(EPA)%	2	Neck flesh	0.0000
3	4	C20:5n-3(EPA)%	2	Neck flesh	3.2400
4	3	C20:5n-3(EPA)%	2	Neck flesh	2.1173
5	2	C20:5n-3(EPA)%	2	Neck flesh	3.9998
6	1	C20:5n-3(EPA)%	2	Neck flesh	6.1653
1	6	C20:5n-3(EPA)%	3	Neck flesh	4.8790
2	5	C20:5n-3(EPA)%	3	Neck flesh	2.2448
3	4	C20:5n-3(EPA)%	3	Neck flesh	4.3853
4	3	C20:5n-3(EPA)%	3	Neck flesh	0.7094
5	2	C20:5n-3(EPA)%	3	Neck flesh	0.0000
6	1	C20:5n-3(EPA)%	3	Neck flesh	4.1840
1	6	C20:5n-3(EPA)%	4	Neck flesh	0.0000
2	5	C20:5n-3(EPA)%	4	Neck flesh	0.0000
3	4	C20:5n-3(EPA)%	4	Neck flesh	0.0000
4	3	C20:5n-3(EPA)%	4	Neck flesh	0.0000
5	2	C20:5n-3(EPA)%	4	Neck flesh	0.0000
6	1	C20:5n-3(EPA)%	4	Neck flesh	0.0000

Table 9. The percentage Docosahexaenoic acid present in both the clean head and neck flesh sections per category for each of the six days of sampling on the third boat trip.

Day sampled	Days on Trawler	Measurement	Category	Sample name	C22:6n-3(DHA)(%)
1	6	C22:6n-3(DHA)%	1	Clean head	15.0623
2	5	C22:6n-3(DHA)%	1	Clean head	21.7655
3	4	C22:6n-3(DHA)%	1	Clean head	24.8543
4	3	C22:6n-3(DHA)%	1	Clean head	29.5385
5	2	C22:6n-3(DHA)%	1	Clean head	11.6584
6	1	C22:6n-3(DHA)%	1	Clean head	5.5334
1	6	C22:6n-3(DHA)%	2	Clean head	22.3948
2	5	C22:6n-3(DHA)%	2	Clean head	47.7979
3	4	C22:6n-3(DHA)%	2	Clean head	21.7060
4	3	C22:6n-3(DHA)%	2	Clean head	16.8490
5	2	C22:6n-3(DHA)%	2	Clean head	30.0480
6	1	C22:6n-3(DHA)%	2	Clean head	31.7518
1	6	C22:6n-3(DHA)%	3	Clean head	27.2949

Table 9. continued

2	5	C22:6n-3(DHA)%	3	Clean head	17.0596
3	4	C22:6n-3(DHA)%	3	Clean head	2.2371
4	3	C22:6n-3(DHA)%	3	Clean head	35.7421
5	2	C22:6n-3(DHA)%	3	Clean head	21.7477
6	1	C22:6n-3(DHA)%	3	Clean head	25.0152
1	6	C22:6n-3(DHA)%	4	Clean head	29.1209
2	5	C22:6n-3(DHA)%	4	Clean head	35.8221
3	4	C22:6n-3(DHA)%	4	Clean head	0.1180
4	3	C22:6n-3(DHA)%	4	Clean head	7.6531
5	2	C22:6n-3(DHA)%	4	Clean head	14.8714
6	1	C22:6n-3(DHA)%	4	Clean head	38.8815
1	6	C22:6n-3(DHA)%	1	Neck flesh	0.1174
2	5	C22:6n-3(DHA)%	1	Neck flesh	35.5622
3	4	C22:6n-3(DHA)%	1	Neck flesh	18.6550
4	3	C22:6n-3(DHA)%	1	Neck flesh	18.3926
5	2	C22:6n-3(DHA)%	1	Neck flesh	10.4214
6	1	C22:6n-3(DHA)%	1	Neck flesh	24.0885
1	6	C22:6n-3(DHA)%	2	Neck flesh	20.0374
2	5	C22:6n-3(DHA)%	2	Neck flesh	24.8238
3	4	C22:6n-3(DHA)%	2	Neck flesh	30.4533
4	3	C22:6n-3(DHA)%	2	Neck flesh	6.1905
5	2	C22:6n-3(DHA)%	2	Neck flesh	16.5474
6	1	C22:6n-3(DHA)%	2	Neck flesh	18.0760
1	6	C22:6n-3(DHA)%	3	Neck flesh	24.9365
2	5	C22:6n-3(DHA)%	3	Neck flesh	9.0192
3	4	C22:6n-3(DHA)%	3	Neck flesh	21.6479
4	3	C22:6n-3(DHA)%	3	Neck flesh	1.5863
5	2	C22:6n-3(DHA)%	3	Neck flesh	25.0938
6	1	C22:6n-3(DHA)%	3	Neck flesh	17.6312
1	6	C22:6n-3(DHA)%	4	Neck flesh	31.9774
2	5	C22:6n-3(DHA)%	4	Neck flesh	24.1512
3	4	C22:6n-3(DHA)%	4	Neck flesh	30.6672
4	3	C22:6n-3(DHA)%	4	Neck flesh	31.1468
5	2	C22:6n-3(DHA)%	4	Neck flesh	12.5721
6	1	C22:6n-3(DHA)%	4	Neck flesh	21.0608

Table 10. The percentage saturated (SFA), mono-unsaturated (MUFA), n-3 and n-6 fatty acids in the clean head section per category for each of the six days of sampling on the third boat trip.

Day sampled	Days on Trawler	Category	Sample name	Measurement	Value (%)
1	6	1	Clean head	SFA	51.686
2	5	1	Clean head	SFA	49.145
3	4	1	Clean head	SFA	38.966
4	3	1	Clean head	SFA	35.355
5	2	1	Clean head	SFA	37.004
6	1	1	Clean head	SFA	54.378
1	6	2	Clean head	SFA	44.308
2	5	2	Clean head	SFA	21.817
3	4	2	Clean head	SFA	24.968
4	3	2	Clean head	SFA	42.460

Table 10. continued

5	2	2	Clean head	SFA	31.424
6	1	2	Clean head	SFA	27.109
1	6	3	Clean head	SFA	33.820
2	5	3	Clean head	SFA	59.592
3	4	3	Clean head	SFA	49.488
4	3	3	Clean head	SFA	17.168
5	2	3	Clean head	SFA	36.445
6	1	3	Clean head	SFA	19.226
1	6	4	Clean head	SFA	32.238
2	5	4	Clean head	SFA	16.148
3	4	4	Clean head	SFA	70.378
4	3	4	Clean head	SFA	82.191
5	2	4	Clean head	SFA	46.870
6	1	4	Clean head	SFA	14.496
1	6	1	Clean head	MUFA	25.636
2	5	1	Clean head	MUFA	22.041
3	4	1	Clean head	MUFA	30.531
4	3	1	Clean head	MUFA	29.122
5	2	1	Clean head	MUFA	39.609
6	1	1	Clean head	MUFA	17.710
1	6	2	Clean head	MUFA	22.440
2	5	2	Clean head	MUFA	14.954
3	4	2	Clean head	MUFA	43.391
4	3	2	Clean head	MUFA	36.763
5	2	2	Clean head	MUFA	31.133
6	1	2	Clean head	MUFA	34.005
1	6	3	Clean head	MUFA	27.013
2	5	3	Clean head	MUFA	14.533
3	4	3	Clean head	MUFA	39.407
4	3	3	Clean head	MUFA	37.471
5	2	3	Clean head	MUFA	31.394
6	1	3	Clean head	MUFA	41.661
1	6	4	Clean head	MUFA	29.899
2	5	4	Clean head	MUFA	40.328
3	4	4	Clean head	MUFA	22.072
4	3	4	Clean head	MUFA	0.906
5	2	4	Clean head	MUFA	27.426
6	1	4	Clean head	MUFA	39.371
1	6	1	Clean head	6	2.757
2	5	1	Clean head	6	2.906
3	4	1	Clean head	6	4.402
4	3	1	Clean head	6	4.780
5	2	1	Clean head	6	8.367
6	1	1	Clean head	6	19.747
1	6	2	Clean head	6	3.527
2	5	2	Clean head	6	8.130
3	4	2	Clean head	6	5.152
4	3	2	Clean head	6	2.041
5	2	2	Clean head	6	6.493
6	1	2	Clean head	6	6.849
1	6	3	Clean head	6	4.797
2	5	3	Clean head	6	4.145

Table 10. continued

3	4	3	Clean head	6	7.992
4	3	3	Clean head	6	9.164
5	2	3	Clean head	6	5.591
6	1	3	Clean head	6	13.901
1	6	4	Clean head	6	5.815
2	5	4	Clean head	6	7.531
3	4	4	Clean head	6	4.354
4	3	4	Clean head	6	7.995
5	2	4	Clean head	6	6.943
6	1	4	Clean head	6	6.941
1	6	1	Clean head	3	19.921
2	5	1	Clean head	3	25.909
3	4	1	Clean head	3	26.101
4	3	1	Clean head	3	30.743
5	2	1	Clean head	3	15.019
6	1	1	Clean head	3	8.165
1	6	2	Clean head	3	29.725
2	5	2	Clean head	3	55.099
3	4	2	Clean head	3	26.489
4	3	2	Clean head	3	18.736
5	2	2	Clean head	3	30.950
6	1	2	Clean head	3	32.037
1	6	3	Clean head	3	34.369
2	5	3	Clean head	3	21.730
3	4	3	Clean head	3	3.113
4	3	3	Clean head	3	36.197
5	2	3	Clean head	3	26.569
6	1	3	Clean head	3	25.212
1	6	4	Clean head	3	32.048
2	5	4	Clean head	3	35.993
3	4	4	Clean head	3	3.196
4	3	4	Clean head	3	8.908
5	2	4	Clean head	3	18.761
6	1	4	Clean head	3	39.192

Table 11. The percentage saturated (SFA), mono-unsaturated (MUFA), n-3 and n-6 fatty acids in the neck flesh section per category for each of the six days of sampling on the third boat trip.

Day sampled	Days on Trawler	Category	Sample name	Measurement	Value (%)
1	6	1	Neck flesh	SFA	56.487
2	5	1	Neck flesh	SFA	35.894
3	4	1	Neck flesh	SFA	39.700
4	3	1	Neck flesh	SFA	55.217
5	2	1	Neck flesh	SFA	46.551
6	1	1	Neck flesh	SFA	51.816
1	6	2	Neck flesh	SFA	50.345
2	5	2	Neck flesh	SFA	26.563
3	4	2	Neck flesh	SFA	38.700
4	3	2	Neck flesh	SFA	52.748

Table 11. continued

5	2	2	Neck flesh	SFA	45.585
6	1	2	Neck flesh	SFA	52.452
1	6	3	Neck flesh	SFA	34.545
2	5	3	Neck flesh	SFA	46.057
3	4	3	Neck flesh	SFA	49.835
4	3	3	Neck flesh	SFA	40.780
5	2	3	Neck flesh	SFA	33.976
6	1	3	Neck flesh	SFA	50.536
1	6	4	Neck flesh	SFA	29.952
2	5	4	Neck flesh	SFA	39.043
3	4	4	Neck flesh	SFA	34.186
4	3	4	Neck flesh	SFA	37.761
5	2	4	Neck flesh	SFA	36.042
6	1	4	Neck flesh	SFA	35.781
1	6	1	Neck flesh	MUFA	13.702
2	5	1	Neck flesh	MUFA	23.506
3	4	1	Neck flesh	MUFA	14.348
4	3	1	Neck flesh	MUFA	20.540
5	2	1	Neck flesh	MUFA	26.895
6	1	1	Neck flesh	MUFA	13.779
1	6	2	Neck flesh	MUFA	22.292
2	5	2	Neck flesh	MUFA	41.457
3	4	2	Neck flesh	MUFA	25.026
4	3	2	Neck flesh	MUFA	32.683
5	2	2	Neck flesh	MUFA	24.978
6	1	2	Neck flesh	MUFA	19.625
1	6	3	Neck flesh	MUFA	28.907
2	5	3	Neck flesh	MUFA	38.968
3	4	3	Neck flesh	MUFA	14.459
4	3	3	Neck flesh	MUFA	42.145
5	2	3	Neck flesh	MUFA	33.989
6	1	3	Neck flesh	MUFA	22.048
1	6	4	Neck flesh	MUFA	29.632
2	5	4	Neck flesh	MUFA	28.422
3	4	4	Neck flesh	MUFA	28.027
4	3	4	Neck flesh	MUFA	26.002
5	2	4	Neck flesh	MUFA	39.086
6	1	4	Neck flesh	MUFA	32.546
1	6	1	Neck flesh	6	2.528
2	5	1	Neck flesh	6	4.300
3	4	1	Neck flesh	6	4.175
4	3	1	Neck flesh	6	2.434
5	2	1	Neck flesh	6	13.384
6	1	1	Neck flesh	6	3.998
1	6	2	Neck flesh	6	2.881
2	5	2	Neck flesh	6	5.247
3	4	2	Neck flesh	6	1.163
4	3	2	Neck flesh	6	5.872
5	2	2	Neck flesh	6	8.677
6	1	2	Neck flesh	6	3.403
1	6	3	Neck flesh	6	4.758
2	5	3	Neck flesh	6	3.564

Table 11. continued

3	4	3	Neck flesh	6	9.516
4	3	3	Neck flesh	6	13.881
5	2	3	Neck flesh	6	6.520
6	1	3	Neck flesh	6	5.046
1	6	4	Neck flesh	6	5.859
2	5	4	Neck flesh	6	7.896
3	4	4	Neck flesh	6	4.291
4	3	4	Neck flesh	6	4.843
5	2	4	Neck flesh	6	11.634
6	1	4	Neck flesh	6	10.312
1	6	1	Neck flesh	3	27.283
2	5	1	Neck flesh	3	36.300
3	4	1	Neck flesh	3	41.777
4	3	1	Neck flesh	3	21.809
5	2	1	Neck flesh	3	13.170
6	1	1	Neck flesh	3	30.407
1	6	2	Neck flesh	3	24.483
2	5	2	Neck flesh	3	26.733
3	4	2	Neck flesh	3	35.111
4	3	2	Neck flesh	3	8.698
5	2	2	Neck flesh	3	20.760
6	1	2	Neck flesh	3	24.520
1	6	3	Neck flesh	3	31.791
2	5	3	Neck flesh	3	11.411
3	4	3	Neck flesh	3	26.190
4	3	3	Neck flesh	3	3.194
5	2	3	Neck flesh	3	25.515
6	1	3	Neck flesh	3	22.370
1	6	4	Neck flesh	3	34.557
2	5	4	Neck flesh	3	24.638
3	4	4	Neck flesh	3	33.497
4	3	4	Neck flesh	3	31.394
5	2	4	Neck flesh	3	13.239
6	1	4	Neck flesh	3	21.361