Three phase separation of waste from salmon slaughteries

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Scope:
Trials of a device for separating the solid waste from fish slaughteries, estimation of the environmental impact of the treated waste and the nutritional suitability, for re-use, of the separated waste products.

Key-words:

Fat, separation, salmon slaughtery, waste, nutrients, environmental impact.

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Three phase separation of waste from salmon slaughteries

Tre fase separasjon av avfall fra lakseslakterier

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1. Foreword

Through funds provided by the Norwegian Technical Research Council, Rogaland Research and NORCONSERV have developed a new niche of co-operation. The strategic technology programme (1991-1993) carried out by the two institutions was aimed directly towards the processing of salmon and salmon slaughteries. A strong link was formed with the salmon slaughtery/processing plant Ryfisk, located in the Hjelmeland area, near Stavanger, Norway. All projects were carried out in close co-operation with this industrial partner.

During the programme period, a number of different aspects of salmon slaughtering and processing have been investigated. During this investigation, a number of key problems have been revealed. One of the major problems has been the disposal/treatment of waste. This project investigates the possibilities of utilizing three phase separation technology locally - in a salmon slaughtery - to upgrade the waste to salmon oil and feed components. It also examines the potential pollution problems that could be caused by disposal of the aqueous fraction - the stickwater.

The authors are grateful to **Bent Ludvigsen** (Alfa Laval) for technical advice and permission to use Figures 1 - 3, **Johan Livastøl** for permission to use the facilities and **Jan Merland** and **Sigurd Rød** for practical assistance. Funding from: the **Norwegian Research Council** (project STP.28611); **Alfa Laval**, Søborg, Denmark; **Ryfylke DU**, Hjelmeland; **Ryfisk A/S**, Hjelmeland; and **Agro Fellesslakteri**, Forus, Stavanger, is gratefully acknowledged.

2. Contents

3. Abstrakt - Norsk

En ny metode for utnyttelse av ferskt avfall fra lakseslakterier er undersøkt. Ved hjelp av et anlegg bestående av en skrapevarmeveksler og en dekanter sentrifuge, ble oppmalt slakteriavfall separert i tre fraksjoner: fast fase (grax), vannfase (limvann) og fettfase (olje). Sammensetningen av de ulike fraksjonene ble undersøkt. Dessuten ble limvannets forurensnings-potensiale og de ernæringsmessige kvaliteter av grax og olje undersøkt nærmere. Prosessen var velegnet til å oppgradere/foredle ferskt fiskeavfall. Produktene hadde jevn sammensetning, selv med vært ulike sammensetninger av avfall. Prosessen var forøvrig svært skånsom m.h.t. temperatur (95°C i 4-5 min.), og med ferskt råstoff ga den produkter av høy kvalitet. En blanding av grax og limvann var velegnet som proteinkilde i grisefôr.

Den miljømessige belastningen fra limvannet, målt v.hj.a. kjemisk oksygenforbruk, biologisk olksygenforbruk, tørrstoff, totalt nitrogen og totalt fosfor, var betydelig, men svært varierende. Et tonn slo kunne medføre et utslipp tilsvarende 450 mennesker/døgn, beregnet på basis av biologisk oksygenforbruk. Et tonn hel fisk kunne medføre et utslipp på 187 mennesker/døgn, beregnet på samme basis. Tørrstoffverdier ville gitt grunnlag for enda høyere verdier. Til forskjell fra direkte utslipp i resipienten, fjerner rekombinering av limvann og grax alle miljøbelastninger forårsaket av limvannet. Det er derfor en miljømessig svært gunstig prosedyre.

Tre-fase-separasjonsanlegget som ble brukt i denne undersøkelsen løste effektivt lakseslakteriets avfallsproblem. Mer arbeid gjenstår for effektivt å kunne forutsi og modellere prosessens effektivitet og produktenes kvalitet og sammensetning, spesielt hvis det er tale om andre råstoffkilder og endrede lokale forhold.

4. Abstract - English

A new method of utilizing fresh waste from salmon slaughteries was investigated. Using a scraped surface heat exchanger and a decanter centrifuge, solid minced salmon wastes were separated into three fractions; solid (grax), aqueous (stickwater) and lipid (oil). The general composition of the three effluent fractions was examined and their pollution (stickwater) or nutrition potential (grax and oil) was estimated.

The process seemed well suited to the upgrading of solid fish waste. The product composition was uniform, even between different proportions of waste components. The process was fairly thermally gentle (heating to 95°C for 4 - 5 min). High quality products were obtained from fresh raw materials. A combination of the solid and aqueous fractions was well suited as a protein source in pig feed.

The environmental loading from the stickwater phase, as estimated using COD, BOD7, TS, TN and TP, was great but intermittent. 1 t of viscera produced a BOD population equivalent of 450 people.days and 1 t of whole fish produced a population equivalent of 187 people.days. TS loadings were higher. Recombination of the stickwater into the solid phase, as opposed to direct discharge to the recipient, eradicated the environmental loading from the stickwater phase and as such can be considered to be an environmentally sound policy. The three-phase separator, as used in this study, effectively solved the environmental impact problem resulting from solid waste from this salmon slaughtery. More work would be required to reliably predict and model the general environmental efficacy of the process as applied to other locations and management regimes, with respect to varying input components and local conditions.

5. Introduction and aims

Waste from fish slaughteries is becoming an increasingly difficult problem. For several reasons constraints are now being placed on the quantity of potentially polluting substances which can be released directly back into the environment. These reasons include the need to maintain nutrient inputs, in the form of metabolisable phosphorus and nitrogen compounds, below the carrying capacity of the local aquatic recipient. A further major reason for limiting and treating wastes from fish slaughteries is the reduction in the potential for the transfer of pathogenic diseases to wild and farmed fish stock.

Different types of waste result from fish slaughtering activities, such as: solid wastes, including frames (bones) and carcasses (mainly flesh and internal organs); and blood water, resulting from bleeding and washing activities. Rather than merely wasting these by-products, attempts are made to use this material as a component of animal feeds. For several years, the waste from many of the Norwegian salmon slaughteries has been made into silage by the addition of formic acid. This is then collected and further processed into mink feed by specialist feed processors. With few other acceptable waste disposal alternatives available for the salmon slaughteries, these feed producers have increased the fees for removing the waste. Hence, the salmon processors no longer have the waste removed free of charge, with only the cost of acid to pay. Currently, waste removal amounts to a significant sum.

The increasing removal costs initiated exploration of novel technologies for the alternative utilisation of salmon slaughtery waste. A local pig feed processor recently produced a feed based on the waste from restaurants and catering establishments and was looking for a suitable protein source derived from industrial waste.

Fish is a good source of protein, but a problem with its use in pig feed, is the sensitivity of pig flesh to fish oil taint and rancidity. Currently, several studies are being conducted to determine the maximum tolerable fish lipid content in pig feed (Kjos, pers. comm.). This limits the quantity of fresh waste or silage from fish processing plants, which can be used. While the waste from most other fish processing industries tends to be vary seasonally, with respect to both quality and quantity, salmon slaughteries commonly generate high quality waste at a constant rate. The fat content of the waste is however too high, as stated above, so this has to be separated prior to use in pig feed.

This can be achieved by use of adequate process equipment and methods. One such method is possible using equipment manufactured by Alfa-Laval. The unit, described in section 5.1, separates the raw waste into three different phase products: solid (grax); oil (fett); and stickwater (limvann). The stickwater is then commonly recombined with the solid phase for 2 reasons. Firstly this allows the solid phase to be pumped more easily and secondly the fat content of the combined mixture is reduced relative to the solid phase and the protein content is increased. There are potentially several advantages conferred by this 3 phase separation and recombination strategy:

- Production of a saleable, pure, fish oil suitable for the food, pharmaceutical, or cosmetics industry.
- Reduction in the quantity of silage material which must be paid to be removed for use as animal feed.
- Improved quality of the silage material, with respect to fat and protein levels, which are more suitable for use in a wider range of animal feeds.
- Improved silage material may lead to a greater market demand, resulting in further reductions in transport costs, possibly even positive economic benefits.

- Reduction, or more correctly the termination, in the effluent from the raw waste fish which reaches the recipient water body, in this case seawater fjord bordering the slaughtery.

The aim of this study was to test the validity of these 5 expected advantages. Primarily, the expected effluent loading of the wastes, otherwise disposed of to the recipient, and the nutritional composition of the by-products of the separation and their suitability for incorporation into animal feeds or human usage, were examined.

6. Materials and methods

6.1. Equipment

Alfa Laval Fish and Meat Engineering A/S is a major producer of food processing equipment. Fat separation, mainly within the dairy and fish oil industries, has been one of their key areas for a number of years. During the last few years Alfa Laval has been working with the separation of fat from fish silage generated at salmon slaughteries. Based on this experience, a plant for the 3 phase separation of salmon slaughtery waste, used in this study, was constructed. It consisted of the following components (set up as shown in Figure 1):

- Raw material hopper, for feeding of waste into the mincer.
- Raw material mincer, with gearing, belt drive and an 11 kW electric motor.
- Intermediate tank I; stainless steel, 300 l volume
- Feed pump for the contherm cooker, driven by a 2.2 kW electric motor and variable speed drive.
- Contherm cooker. Type 6x9, insulated scraped-surface heat exchanger indirectly heated by steam and provided with a 7.5 kW electric motor.
- Intermediate tank II. Stainless steel, 300 l volume, provided with an agitator driven by a 1.1 kW electric motor and a lever controller regulating the speed of the decanter feed pump.
- Feed pump for the decanter, driven by a 2.2 kW electric motor with variable speed drive.
- Alfa Laval decanter Type NX 409-11G (described below).
- Solid and stickwater phase collection tank.
- Oil phase collection tank.

All parts coming into contact with the product were made of stainless steel. The conveyor surface was hard, and driven by a 15 kW electric motor, with an overload guard and gear box.

The main part of the plant was the decanter centrifuge (Figures 2 and 3). The type 409 was designed to operate in animal and fish processing industries. The heated waste suspension entered the decanter, and was separated into a solid phase (grax), a water phase (stick water) and a lipid phase (oil).

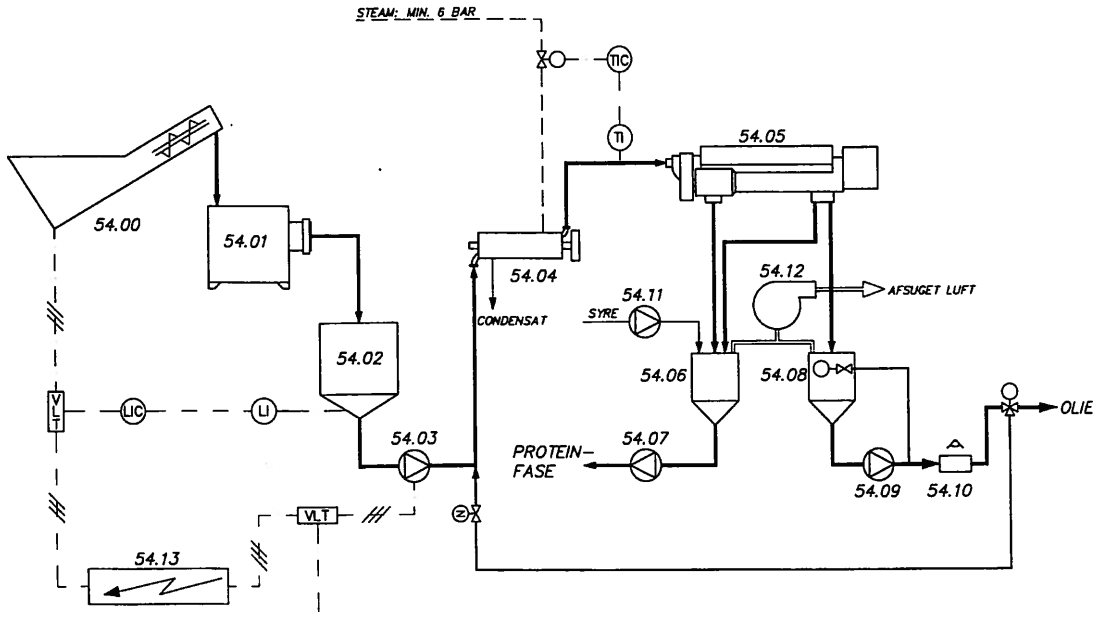


Figure 1: Flow diagram of waste separation unit (courtesy Alfa Laval)

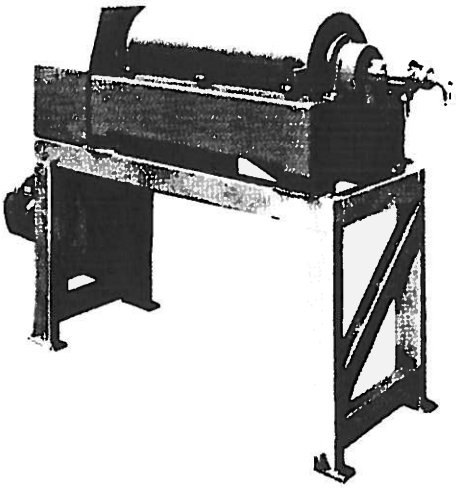


Figure 2: Alfa Laval decanter centrifuge NX 409

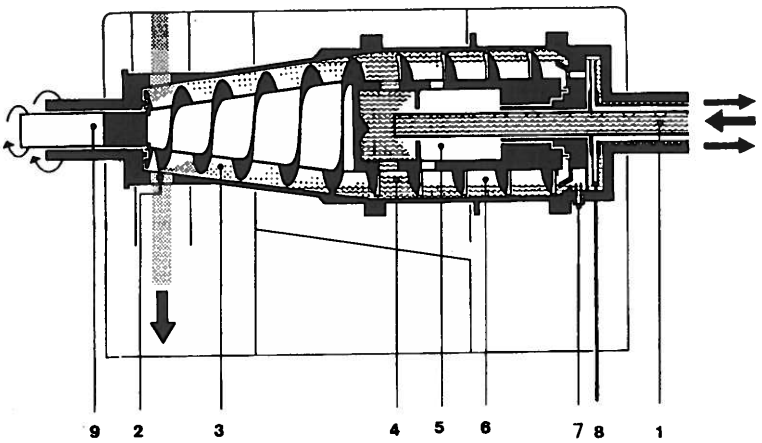


Figure 3: Functional cutaway of decantor rotor (courtesy of Alfa Laval). *Key: 1. drive shaft; 2. solids discharge ports; 3. tapered section for the discharge of solids; 4. solids deposited on rotor wall; 5. screw conveyor; 6. clarified liquid; 7. heavy liquid outlet; 8. centripetal pump for oil/fat; 9. conveyor drive shaft.*

6.2 Plant operation

The slaughtering of fish and their subsequent processing is a discontinuous process. A batch of fish will be delivered live from a farm. The fish will then be pumped into racks for CO_2 anaesthetisation, followed by bleeding. The fish are then transported automatically into the factory for processing, which may include, rejection of inadequate quality fish, gutting, filleting, washing, head removal, packaging and preservation.

Significant quantities of waste blood water and solids are produced. The solid wastes, which can include, whole rejected fish, heads, viscera (guts), gut contents, filleted bones (frames), offcuts, skin and occasionally species other than Atlantic salmon (Salmo salar), such as saithe (Pollachius virens). This raw material was stored in approximately 650 l plastic tanks prior to treatment. The constitution in each tank was highly variable, depending on the dominant processing technique employed. During this study, two forms of operation were investigated: normal operation in which the constitution of the raw waste was variable (samples 1 - 5) and controlled operation in which only one type of constituent was placed in a particular tank (samples 6 - 7). The former form of operation was more representative of the usual operating conditions, but the latter form enabled a controlled investigation.

After a short decanter start-up period, a tank, containing the raw waste material was raised, using a fork-lift truck, and emptied into the plant feed hopper at a height of approximately 2.5 - 3 m.

From this hopper, material was screw-fed batch-wise into the mincer. Gravity maintained a flow into the screw. Output from the mincer was stored in bin prior to decanting. Manual management of the mincer was discontinuous and independent of the decanter operation. The mincer was driven until the output bin was filled and not then restarted until the bin was almost empty.

From the mincer output bin, the waste was pumped into the heat exchanger where it was warmed to approximately 95°C, and then on into the decanter centrifuge. The equipment comprising the decanter plant is described in the previous section. Three outputs normally issued from the decanter. The solid phase slid down a stainless steel ramp into a collection bin. The stickwater was led into this solid phase prior to discharge from the decanter. The oil phase was discharged separately through a pipe into a covered collection container. During operation, the output of the oil phase was continuously monitored using a light detection system. Oil of inadequate quality, i.e. not completely separated, as determined by low clarity, was recycled back into the decanter until such time that the clarity improved and an automatic valve re-opened allowing the oil to be discharged.

When the solid/stickwater waste tank was almost full, normally at the end of an input batch, it was carried by fork-lift and tipped into the ensilation tank. Adequately ensiled material was then pumped into a silage storage silo, to await collection, or to be remixed with incoming material.

The operation of the plant from input of raw waste to storage of silage was accomplished by one man working full-time. The management of the decanter unit was automatic, though several functions could be manually over-ridden.

6.3. Sample protocol

The following procedure was used to take and store samples for subsequent analysis. A sample report form (Figure 4) was used to maintain consistency between different field personnel.

Prøvetakingsskjema

Prosjekt: Utprøving av Alfa-Laval Fettavskiller

Serienr. (1, 2, 3, 4, 5): _____ Skal skrives på prøveflasker!
F.eks.: 1A

Prøvenr. (A, B, C): _____ Skal skrives på prøveflasker!

Dato: _____ Kl.: _____

Prøvetaker: _____

Innstillinger på prosess-utstyr:

Temperatur: _____ °C

Annet/Kommentarer:

Mengdeberegninger:

Råstoff:	Ryggbein	Hel fisk	Hoder	Slo	Skinn
ca. % fordeling	_____ %	_____ %	_____ %	_____ %	_____ %

Råstoff: _____ kg

Olje: _____ kg

Limvann: _____ kg

Grax: _____ kg

Disse mengdene registreres i løpet av 15 minutter.

Ta ut 3 prøver (A, B, C) som beskrevet på baksiden, i løpet av registreringsperioden (15 min.)

Figure 4: Field work data form

Each sample set was assigned a number. Within each set, each individual sample was assigned a letter. The date, time, person, process temperature and other relevant comments, e.g. deviations from normal procedure, were noted for each sample set. Information received from the slaughtery personnel enabled an estimate of the proportion of various raw materials within each input batch. The dimensions of the raw material tank were measured and from this its total volume capacity was calculated. The actual volume of raw material in partially filled tanks was similarly calculated.

Prior to sampling and measurements, time was allowed for the decanter operation to reach a steady state and to ensure that matter from a previous batch of raw material had completely passed through the plant. The flow rates of the output phase were then measured and the total time per batch that each phase flowed was noted. From this, an estimate of the total mass flow of input and output phases, and the proportion of the total output, of which each phase comprised, was calculated. The density of each phase was known (B. Ludvigsen, pers. comm.), so the total weight of each phase was calculated, and noted on the sample forms.

Samples for later analysis were taken during steady state operation periods. Firstly, approximately 0.5 kg of minced raw material was collected, into a sealed plastic bag, from the mincer output bin. Care was taken to ensure that a homogenous, representative sample was taken from several locations within the bin. Similarly, a homogenous 0.5 kg of the solid output was sampled into a plastic bag. Prior to and during the taking of this sample, the stickwater was not recombined with the solid fraction. During this time the stickwater flow was diverted to a collection bucket. From this bucket, 1 l of stickwater was sampled into a glass bottle, 1 l into a plastic flask and 0.2 l into a plastic bottle. To ensure that a sufficient volume of sample was collected, time was allowed for the froth on the surface of the samples to settle and then the bottles were further filled. Finally 0.25 l of the oil phase was sampled into a sealed plastic bottle.

One sample run took approximately 20 min to complete. Within each sample set, triplicate sample runs, with as little time between each run as possible, were conducted. All bottles were marked with the sample set number, run (A, B, or C) and the contents. The method of sampling sets 6 and 7 adhered strictly to this protocol, though some procedural differences during the sampling of set 1 - 5 occurred. The main difference was that strict triplicate samples may not have been taken: different sample runs may have been taken from different raw material input batches. Later statistical analysis took this into account.

6.4. Analytical methods

A number of analyses were carried out to characterise, both the input (raw material) and the output fractions (water, solid and oil). Of key interest were the main parameters - water protein and fat. Several special parameters were documented, with the aim of estimating the potential pollution effects or nutritional value.

6.4.1. General parameters

Protein was determined using the Kjeldahl method. Fat was extracted using chloroform, methanol and water (Bligh and Dyer, 1959). Moisture content was determined by drying a homogenised sample at 105° C for 24 h.

6.4.2. Pollution parameters

Contaminants used to assess the environmental loading of the stickwater fraction were analysed according to the following Norwegian Standard Methods:

- COD - NS 4748 2/91
- BOD_7 - NS 4749 1/79
- Total solids - 4764 1/80
- Total nitrogen - NS 4743 2/93
- Total phosphorus - NS 4725 3/84

6.4.3. Nutritional parameters

Amino acids

The samples were hydrolysed and analysed as described by Waters (1990).

Fatty acids

The lipid extracts were methylated according to AOAC (1990), method 969.33. A Bligh and Dyer lipid extract (100 mg) was dried and boiled with sodium hydroxide (0.5M, 4 ml). Boron tri-fluoride in methanol (12.5 %, 5 ml) was added, and the solution was kept boiling for an additional 4 min. The methyl esters were extracted into n-heptane and analysed using capillary column GC equipped with a flame ionisation detector.

7. Input

The waste from salmon slaughteries is normally divided in two phases: liquid and solid. The liquid waste consists mainly of blood-water and cooling water, from the slaughtering process. It amounts to more than three times the weight of raw material (Skåra *et al.*, 1993) and is hence dilute (1 - 2 % dry matter). It is however a potential source of viral and microbial fish diseases. Norwegian regulations demand special treatment, to ensure "sterility" prior to discharge into recipient. General process water from cleaning etc. is treated in the same way.

The solid waste commonly comprises approximately 15 % of the weight of the slaughtery raw material. This figure increases rapidly with further processing, e.g. filleting.

7.1. Raw material

Tests described in this study were conducted in a salmon specific slaughtery. This limits the number of possible waste compositions.

In such a slaughtery, the main solid waste streams are:

- Down graded fish
- Viscera

Further processing, i.e. filleting and portioning, is however increasing in Norwegian slaughteries. These processes generate:

- Heads
- Off-cuts
- Skin
- Frame bones

The waste stream from a salmon slaughtery/processing plant will vary in composition, depending on production, volume and season. Test runs conducted in this study reflect this, and the varying compositions are estimated.

7.1.1. Results

The weight composition of the solid waste input and the output fractions was estimated, and the main chemical parameters; water, protein and fat-content were determined. The results are presented in Table 1 and Figure 5.

Table 1: Raw material constitution, chemical composition and quantities of outflow fractions.

Sample number	*1A*	*1B*	*2A*	*2B*	*2C*	*2D*	*3A*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*6*	*7*
Raw material																
Whole fish (%)	100		10		100*		80	70				25	5		100	
Heads (%)		50	40	20		20		20		70		25	50			
Viscera (%)									100		100			100		100
Frame (%)												25				
Offcuts (%)		50	50	80		40	20									
Skin (%)						40				30		25	45			
Saithe (%)								10								
In/Outflow quant.																
Raw inflow (kg)	210	225	241		188		158		168	230	230	250	320	290	650	610
Outflow fractions																
Oil (kg)	20	48	51		21		30		54	46	63	43	45	72	12	117
Stickwater (kg)	68	68	72		75		69		74	72	70	59	65	79	143	255
Solids (kg)	123	110	118		92		59		40	112	97	148	210	139	495	238
Oil (%)	9	21	21		11		19		32	20	27	17	14	25	2	19
Stickwater (%)	32	30	30		40		44		44	31	30	24	20	27	22	42
Solids (%)	58	49	49		49		37		24	49	42	59	66	48	76	39
Temperature (°C)	89	93	99	92	89	98	93	89		94	94	96	96	95	96	96
Raw material																
Water (%)	71.1	63.5	59.9	60.5	72.7	63.6	62.5	66.1	58.4	59.5	59.0	62.7	62.6	58.2	74	63
Protein (%)	16.8	12.0	13.3	14.6	17.3	12.7	13.7	15.4	6.9	12.2	8.3	13.4	12.9	6.7	18.9	6.9
Fat (%)	9.1	20.8	22.9	20.3	8.2	20.9	19.2	14.5	31.5	24.5	30.4	20.1	21.7	31.7	6.5	26.9

*Presumed value - not found in the field work data forms

In Table 1 it is evident that the water, fat and protein-content of the raw material varied according to the composition. The following ranges were observed:

Water content	58.4 % - 72.7 %
Protein content	6.9 % - 17.3 %
Fat content	8.2 % - 31.7 %.

Viscera had the highest fat (31.7 %) and lowest water content (58.2 %), whereas whole fish had the lowest fat (8.2 %) and highest water content (72.7%). The rest of the samples were combinations of whole fish, viscera, heads, frame-bones etc. The compositions of these samples are relatively comparable, with water contents varying from 59.5 to 66.1 %, protein contents from 12.0 % to 15.4 % and fat contents between 14.5 % and 24.5 %. The relative quantities of the output fractions are illustrated as a bar diagram in Figure 5. Figure 6 shows the relative amounts of oil produced, compared to the fat content of the raw material.

7.1.2. Discussion

The results indicate that the separation process was efficient. Figure 6 shows that most of the fat and the raw material was separated during the process and came out in the lipid fraction.

The capacity of the plant has been estimated at approximately 600 kg/h. A salmon slaughtery with a regular production of 20 t salmon/day generates approximately 3.2 t of waste, which could be processed in 5 h. There is no reason why the plant should not be run for at least 15 h/day, and hence it could easily serve 3 or more salmon slaughteries.

Further improvements in product uniformity should be sought. To obtain stable and uniform products, further testing of raw material composition and process parameters is needed. A higher capacity model of the decanter centrifuge would probably ensure a lower fat content in the grax, but previous experiments have shown that, e.g. a high proportion of skin tends to increase the fat content of the grax. Hence the separator manufacturer recommends that skin be processed in special batches at a reduced capacity.

8. Output

Quantification of flows in a continuous process was difficult. The system must be stabilised prior to sampling and measurements. A measured quantity cannot therefore be input, and the output products measured. Also, since the raw material is heated, water will evaporate during the process. It is therefore difficult to estimate accurate quantities and material balances. During this experiment, the outflow fractions were measured/estimated during a fixed time frame (20 min).

8.1. Solid fraction

Due to a relatively high fat content, silage from salmon processing plants cannot be used directly as a protein source. The solid fraction from the separation process described consists mainly of protein and water. This fraction is of particular interest to feed manufacturers, because it contains high quality protein with an acceptable concentration of marine derived fat.

8.1.1 Results

General composition

The water, protein and fat concentrations in all the samples runs were determined. The results are presented as a proportion of the total solid fraction output, in Table 2.

Table 2: General composition of the solid output fractions.

Sample number	*1A*	*1B*	*2A*	*2B*	*2C*	*2D*	*3A*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*	*6*	*7*
Raw material																
Whole fish (%)	100		10		100*		80	70				25	5		100	
Heads (%)		50	40	20		20		20		70		25	50			
Viscera (%)									100		100			100		100
Frame (%)												25				
Offcuts (%)		50	50	80		40	20									
Skin (%)						40				30		25	45			
Saithe (%)								10								
Solid fraction																
Water (%)	67.3	69.0	67.2	66.5	67.0	65.9	67.6	69.5	71.7	67.6	73.5	67.0	66.1	70.2	68.2	71.7
Protein (%)	26.3	22.6	23.2	25.5	26.5	29.1	23.2	24.8	21.4	25.5	21.4	26.3	26.3	23.7	26.0	22.5
Fat (%)	4.7	5.1	5.0	5.4	4.4	3.4	4.9	3.8	3.9	4.4	3.9	4.9	5.4	4.7	4.2	4.4

*Presumed value - not found in the field work data forms

Even with a considerable raw material composition variability, all the solid output samples appear to have a similar composition (Table 2 and Figure 7). The protein content varied between 21.4 and 29.1 %, and the fat content was commonly maintained below 5 % (with only 2 exceptions).

Figure 5: Relative quantity of output fractions; lipid phase = oil, aqueous phase = stickwater, solid phase = grax, W = whole fish, H = heads, V = viscera, O = offcuts, S = skin.

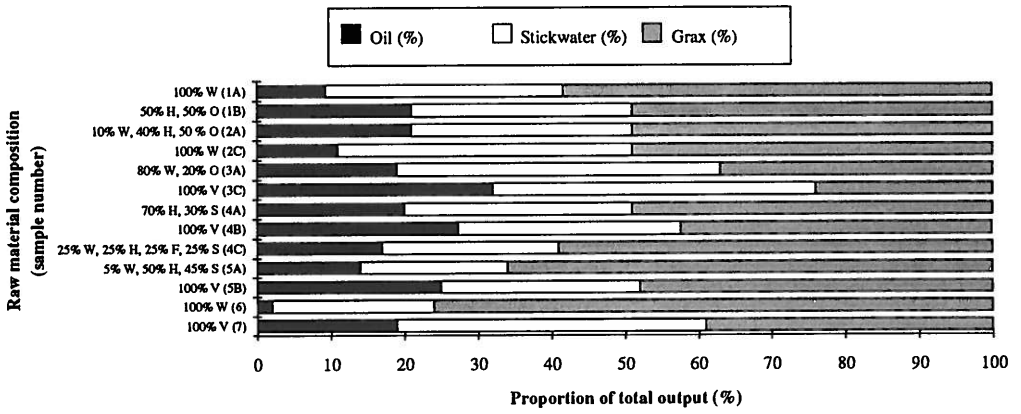


Figure 6: Estimated relative quantities of oil produced compared with the fat content of the raw material

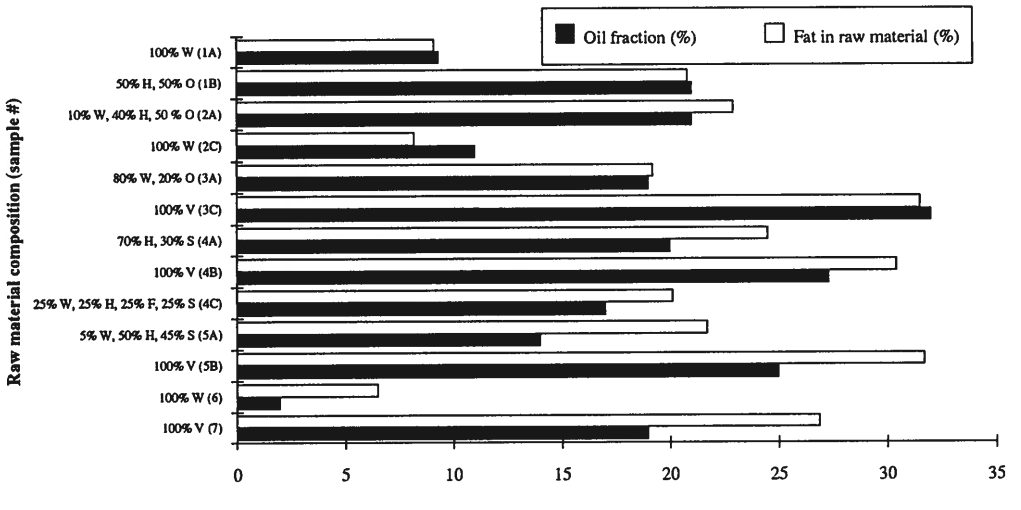
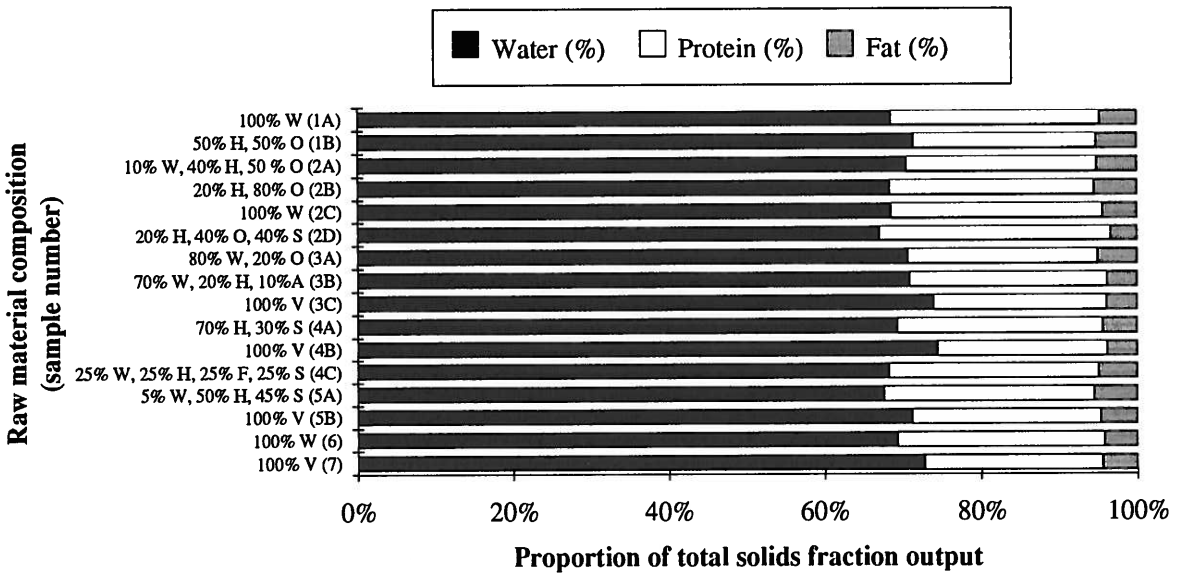


Figure 7: Composition of solid output fraction. W = whole fish, H = heads, V = viscera, O = offcuts, S = skin, A = saithe.



Amino acid composition

As stated above, the amino acid composition is a key parameter used by feed producers for the evaluation of protein quality and the determination of the applications for the use of a protein source. The amino acid composition of two different raw material sources: whole salmon and viscera, and of the resulting solid output fractions is presented in Table 3.

Table 3: Amino acid composition of whole salmon, salmon viscera, and the processed output - grax - from these raw materials (average of 2 samples).

Sample number	6	6	7	7
	Raw material Whole salmon	*Output* Grax	*Raw material* Viscera	*Output* Grax
Alanine	6.1	6.3	5.0	5.9
Arginine	5.9	6.8	4.3	6.5
Aspartic acid	8.5	9.0	8.0	8.4
Cysteine	1.1	1.2	1.6	1.9
Glutamic acid	12.4	13.4	11.1	11.7
Glycine	7.6	7.6	4.6	8.1
Histidine	2.2	2.4	1.9	2.4
Isoleucine	4.3	4.4	4.1	4.3
Leucine	7.1	7.3	6.9	7.3
Lysine	7.3	7.7	5.8	6.5
Methionin	2.9	3.3	2.5	3.0
Phenylalanine	3.8	4.1	3.4	4.4
Proline	4.5	6.4	3.8	5.1
Serine	4.2	4.5	5.9	5.0
Threonine	4.8	5.0	3.8	4.4
Tryptophane	0.9	1.1	0.7	1.2
Tyrosine	3.0	3.3	3.1	3.4
Valine	4.6	4.7	4.5	4.6

8.1.2. Discussion

General composition

The product uniformity of the solid fraction is of vital importance to feed manufacturers, who require a stable fat and protein content. Even though the composition of the solids was found to be uniform in the experiments described in this report, further improvements could probably be achieved by a systematic studies of input sources and output fractions.

A higher capacity model of the decanter centrifuge would probably ensure a lower fat content in the solid phase, but previous experiments have shown that, e.g. a high proportion of skin tends to increase the fat content of the solids. Hence the manufacturer recommends that skin be processed in special batches with a reduced capacity.

Amino acid composition

From the results shown in Table 3 it is evident that none of the essential amino acids are lost during the separation process. Further, since a substantial amount of non-protein nitrogen components, such as ammonia and amines, are removed in the separation process, the amino acid content expressed as a percentage of the total protein content, is greater in the output than in the raw materials. This is common in such processes.

Some differences in composition between the two sources of raw material were evident, e.g. the low content of lysine is typical of highly degradable materials such as the viscera.

Compared to beef blood plasma (Table 4), which is another potential source of protein used by pig feed producers, the solid fraction produced in these experiments contains higher concentrations of Iseoleucine and Methionine, but somewhat lower concentrations of Histidine, Leucine, Phenylalanine and Valine.

Table 4: Average amino acid content of the solid fraction originating from whole salmon and viscera, compared with the amino acid composition of beef blood plasma.

Origin	Grax	Beef blood plasma[a]
Histidine	2.4	3.0 - 3.5
Isoleucine	4.4	1.0 - 3.5
Leucine	7.3	9.2 - 10.1
Lysine	6.5 - 7.7	6.5 - 9.2
Methionine	3.0 - 3.3	0.6 - 1.3
Phenylaline	4.1 - 4.4	5.1 - 5.7
Threonine	4.4 - 5.0	2.6 - 7.1
Tryptophane	1.2	0.6 - 1.9
Valine	4.7	6.8 - 7.4

[a] Ockerman and Hansen (1988)

During this study, no effort was made to document the effects of storage prior to processing. Neither was the storage stability of the products monitored in any way. Both these aspects, and the possibilities of usage for purposes other than pig feed, should be further investigated.

8.2. Stickwater-fraction

8.2.1. Results

The main environmental loading assessment parameters, chemical oxygen demand (COD), biochemical oxygen demand after 7 days incubation (BOD_7), total solids (TS), total nitrogen (TN) and total phosphorus (TP) of each of the sample runs were determined. The results, with respect to the input raw material, are shown in Tables 5a and b. Sample numbers are consistent with those used throughout this study, so comparison of results with data described in other sections is possible.

Table 5a: Stickwater fraction raw input quantities and output water quality results

Sample number	1A	1B	2A	2B	2C	2D	3A	3B	3C	4A	4B	4C	5A	5B
Raw material														
Whole fish (%)	100		10				80	70				25	5	
Heads (%)		50	40	20		20		20		70		25	50	
Viscera (%)									100		100			100
Backbone - Frame (%)												25		
Offcuts (%)		50	50	80		40	20							
Skin (%)						40				30		25	45	
Saithe (%)								10						
Stickwater fraction														
COD (mg/l)	88953	85960	132076	109051	103772	192677	192574	98568	77344	196098	101966	179466	108871	162992
BOD7 (mg/l)	59000	56500	80900	76000	62000	132000	105500	60000	46000	86700	60000	85800	74000	82800
TS (g/l)	86	62	94	100	87	152	138	88	53	121	82	129	94	131
TN (mg/l)	1600.00	3170.00	276.00	786.00	336.00	45.80	18.43	1050.00	2760.00	21.00	216.00	13.19	486.00	12.80
TP (mg/l)	1830	684	1420	1350	1920	756	1210	1970	898	1300	1070	1140	1660	1640

Table 5b: Stickwater fraction raw input quantities and output water quality results

Sample number	6A	6B	6C	6 mean	6 se	7A	7B	7C	7 mean	7 se
Raw material										
Whole fish (%)	100	100	100	100						
Heads (%)										
Viscera (%)						100	100	100	100	
Backbone - Frame (%)										
Offcuts (%)										
Skin (%)										
Saithe (%)										
Stickwater fraction										
COD (mg/l)	117961	95388	107656	107002	6524	172922	161075	175306	169768	4400
BOD7 (mg/l)	68000	58000	68000	64667	3333	74000	84200	87100	81767	3973
TS (g/l)	101	91	92	95	3	121	114	121	119	2
TN (mg/l)	9.30	494.00	794.00	432.43	228.61	14.35	12.03	13.19	13.19	0.67
TP (mg/l)	2020	1950	1950	1973	23	1520	1450	1570	1513	35

It can be seen that the stickwater quality ranged between:

- COD; 4,400 - 196,098 mg/l mean = 122,849 mg/l
- BOD_7; 3,333 - 132,000 mg/l mean = 69,177 mg/l
- TS; 2 - 152 g/l mean = 95 g/l
- TN; 1 - 3170 mg/l mean = 533 mg/l
- TP; 23 - 2,020 mg/l mean = 1,369 mg/l

The concentration of each of these parameters is illustrated as bar diagrams in Figures 8 - 10. Raw inputs for each sample are shown as pie diagrams (key shown in Figure 11) above the respective sample results, for comparison. The small standard errors associated with replicated samples 6 and 7 indicate that the environmental parameter mean results were a reliable estimate. In most cases TP concentrations are greater than TN concentrations. In general 2 groups of COD values were evident: those with a mean of approximately 180,000 mg/l and those with a mean of approximately 110,000 mg/l. The majority of the samples fell into the latter category. BOD_7 values were, in comparison, relatively consistent, fluctuating little from the mean.

To aid the estimation of expected pollution loading at other plants using similar raw products, the relative influence, on the measured environmental parameters, of differing proportions of raw input constitution, was statistically analysed. A summary of the results of the calculation of the degree of correlation between the pollutant loading and the proportion of input constituents is shown in Table 6. The results indicate that none of the environmental parameters could be reliably estimated, at a statistically significant level, from a knowledge only of the constitution of the raw input.

Table 6: Coefficients of correlation (r) between the proportion of various constituents of raw slaughtery waste and the resulting quality of the stickwater fraction

Raw input	Whole fish (%)	p<	Heads (%)	p<	Offcuts (%)	p<	Skin (%)	p<
p<0.05 =		>0.7545		>0.7067		>0.8783		>0.9500
n	7		8		5		4	
COD (mg/l)	-0.3494	NS	0.0636	NS	-0.3546	NS	0.1822	NS
BOD7 (mg/l)	-0.3158	NS	-0.0500	NS	-0.0309	NS	0.4893	NS
TS (g/l)	-0.1906	NS	-0.1977	NS	-0.2614	NS	0.2884	NS
TN (mg/l)	0.5470	NS	0.2429	NS	0.3744	NS	0.0482	NS
TP (mg/l)	0.4707	NS	-0.3471	NS	-0.4802	NS	-0.5395	NS

Raw input	COD (mg/l)	p<	BOD7 (mg/l)	p<	TS (g/l)	p<	TN (mg/l)	p<
p<0.05 =		>0.4973		>0.4973		>0.4973		>0.4973
n	16		16		16		16	
COD (mg/l)	1							
BOD7 (mg/l)	0.8645	p<0.001	1					
TS (g/l)	0.9281	p<0.001	0.9140	p<0.001	1			
TN (mg/l)	-0.7013	p<0.01	-0.6228	p<0.01	-0.7786	p<0.001	1	
TP (mg/l)	-0.2174	NS	-0.2945	NS	-0.0479	NS	-0.3062	NS

Figure 8: Variation in COD and BOD_7 loading of the stickwater fraction with respect to the raw input (+/- SE)

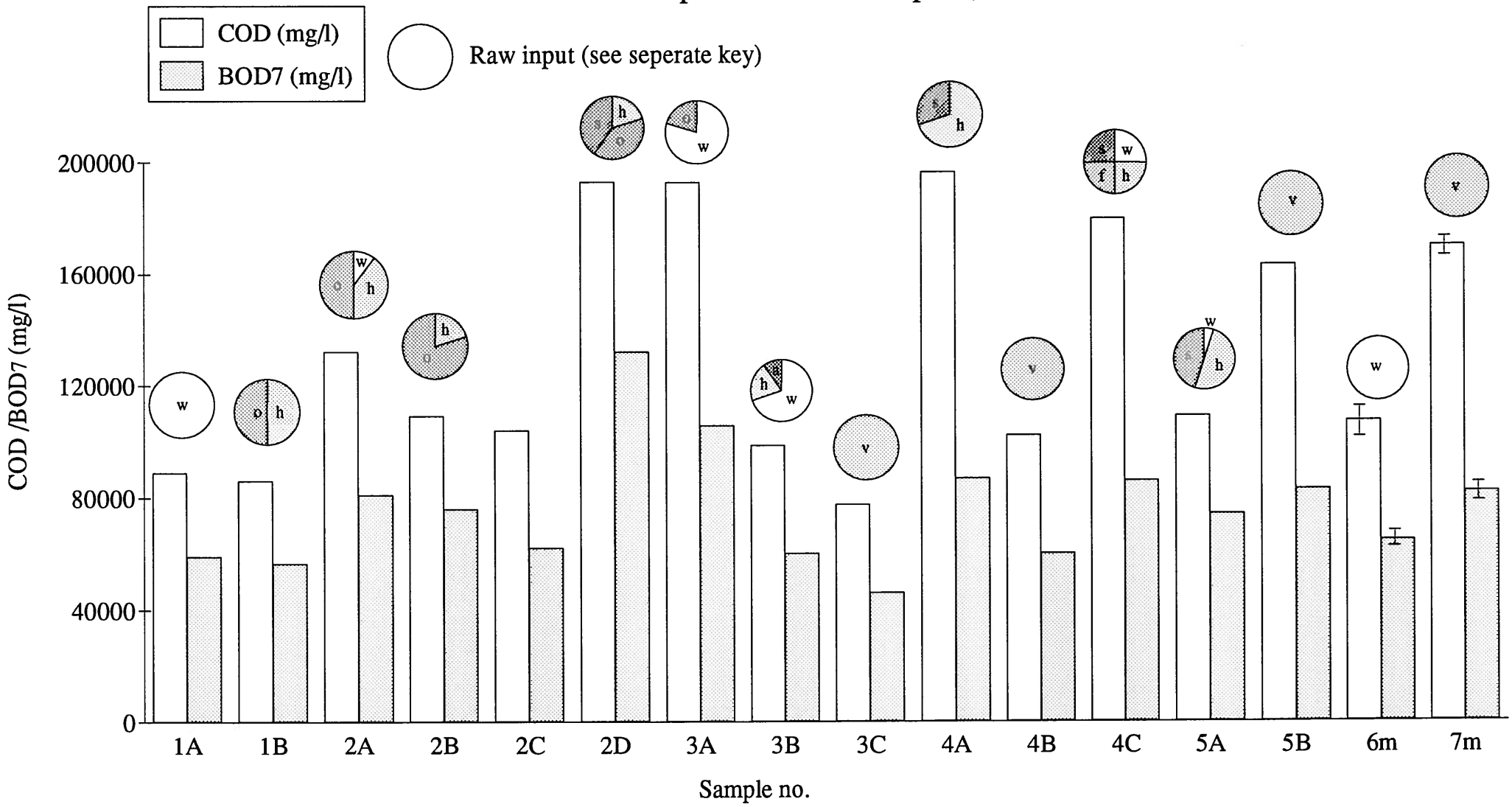


Figure 9: Variation in total suspended solids in the stickwater fraction with respect to the raw input (+/- SE)

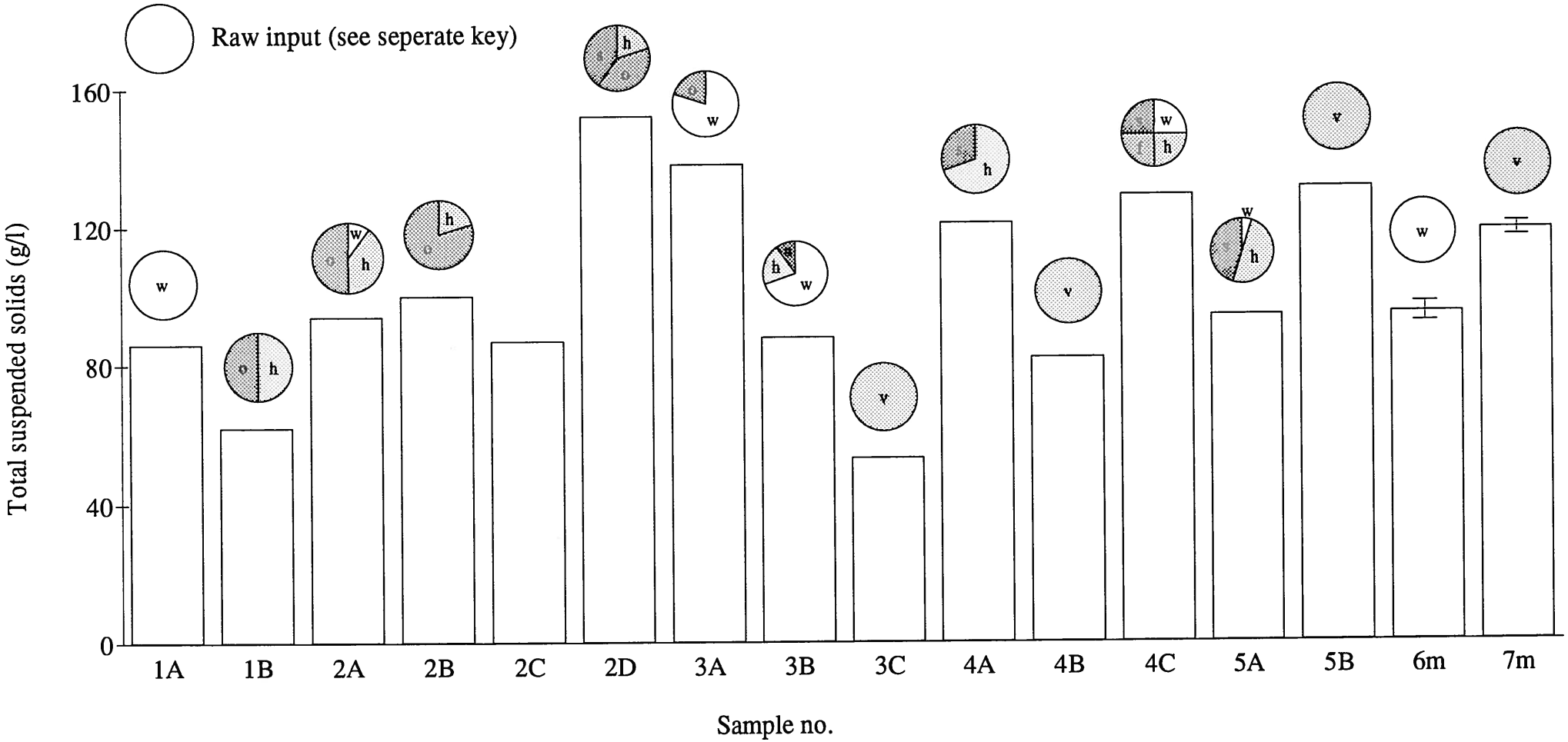


Figure 10: Variation in TP and TN in the stickwater fraction with respect to the raw input (+/- SE)

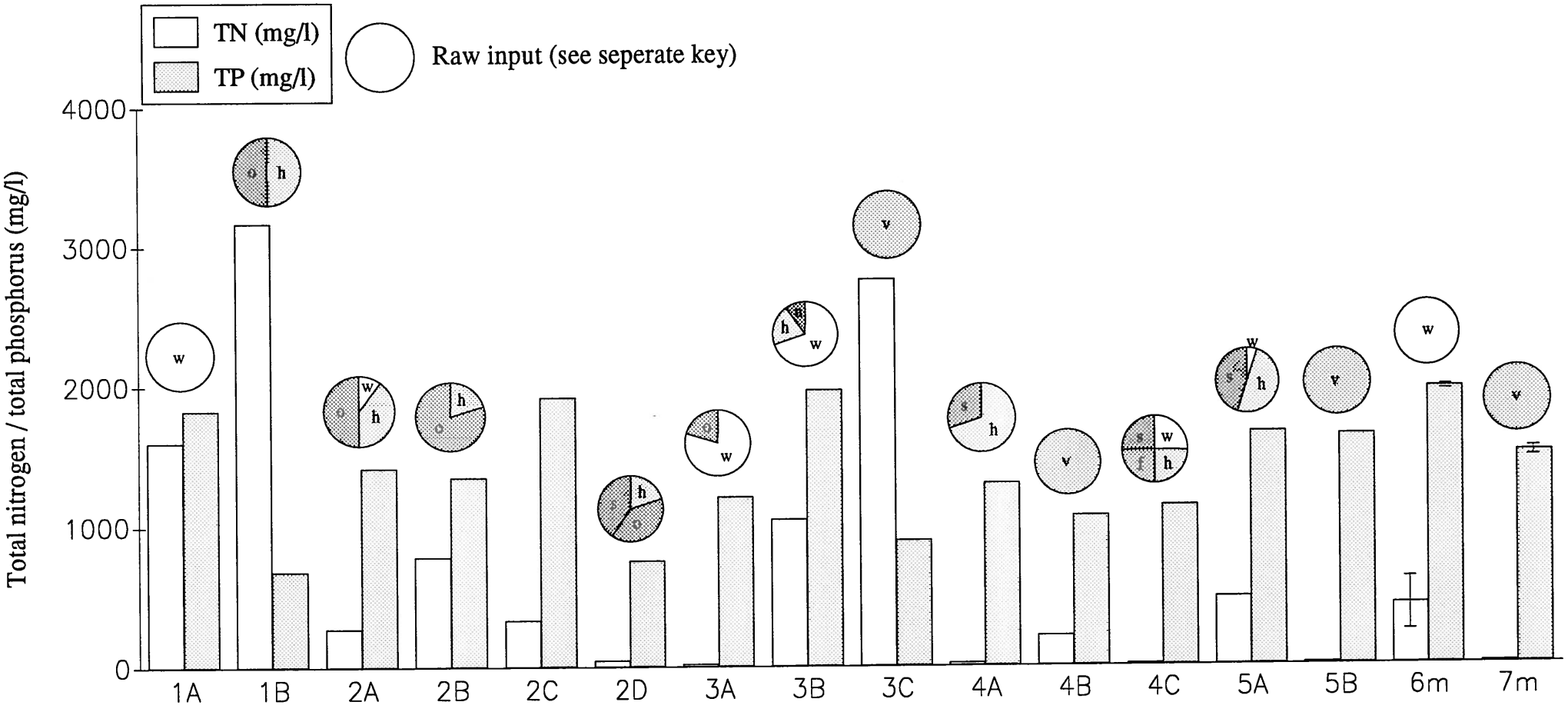


Figure 11: Raw input key to Figures 8 - 10

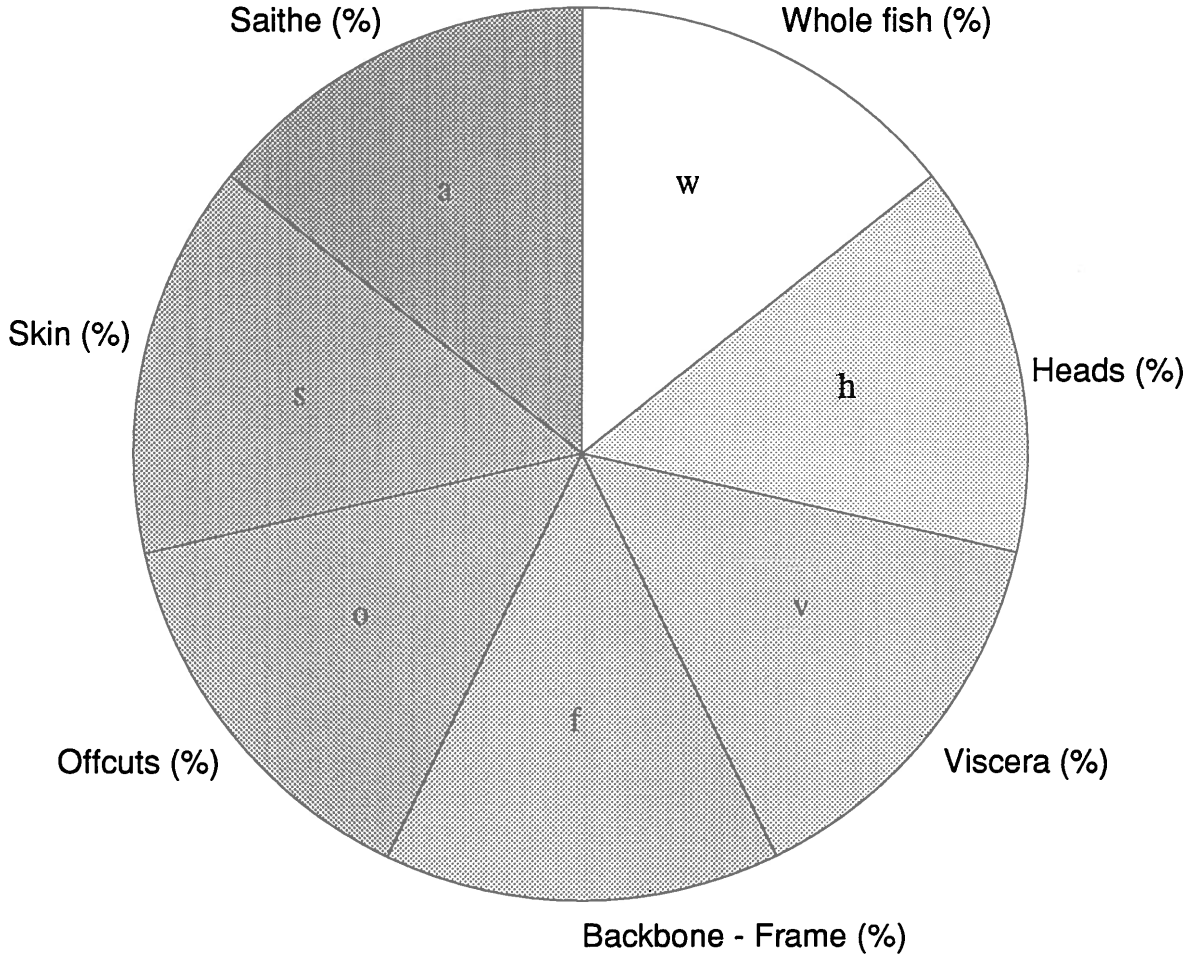


Figure 12 - 14, showing the variation in pollutant loading with respect to the raw input, do however show non-significant trends:

- As the *relative* proportion of offcuts (i.e. with respect to other constituents) in the input increased, the TN tended to increase and the COD, BOD_7 and TS clearly decreased (Figure 12).
- As the *relative* proportion of whole fish in the input increased the TP tended to increase, whilst the COD, BOD_7 and TS remained fairly constant (Figure 13).
- As the *relative* proportion of fish heads increased the TS tended to decrease, whilst the fluctuations in the TN, TP, COD and BOD_7 results were too great to indicate trends (Figure 14).
- The number of samples containing skin was too small to allow even a non-statistical estimate of the its effects on the pollutant loading.

With the exception of TP, the concentrations of the environmental parameters were significantly correlated with each other (Table 6). As COD increased, BOD7 and TS also increased, whilst TN decreased. As BOD_7 increased, COD and TS increased whilst TN decreased. As TS increased, COD and BOD7 increased whilst TN decreased. As TN increased, COD, BOD_7 and TS decreased.

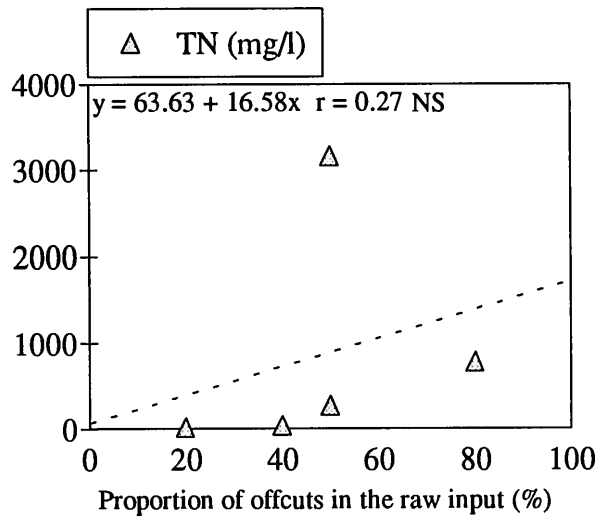
Multiple regression analysis examining the combined effect of all the input constituents simultaneously on the pollution loading failed to indicate any statistically significant trends.

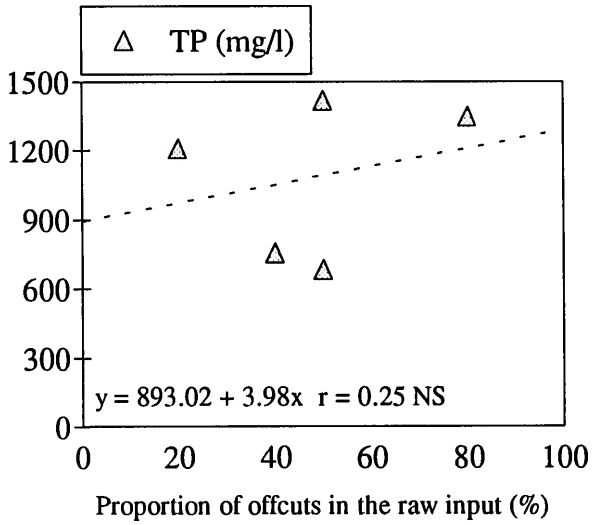
8.2.2. Discussion

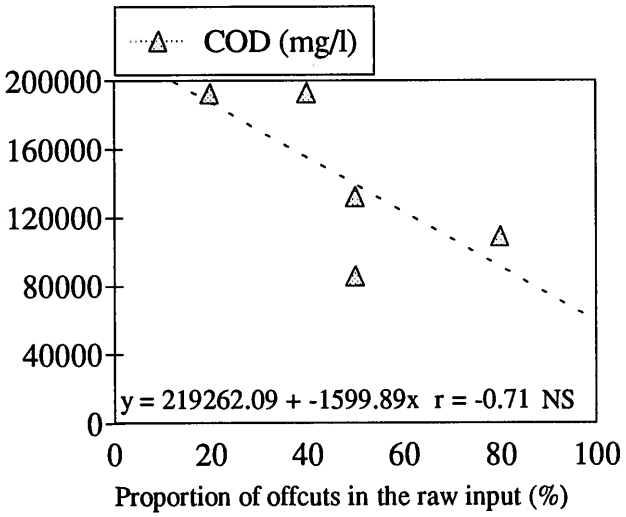
The stickwater fraction was chemically analysed, primarily to determine the expected loading on the environment that would result, should this phase have been disposed of to the recipient. The range of stickwater quality is detailed in the previous section.

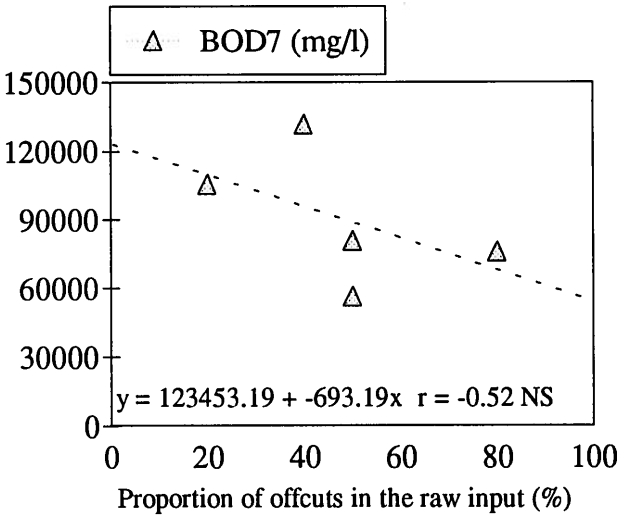
As expected, the COD was higher than BOD_7 results. This was a consequence of the method of COD analysis employed. More compounds can be oxidised chemically than biologically. A ratio COD:BOD of 1:0.65 is common in wastewater studies. The ratio in this study was 1:0.56 indicating that the overall distribution of the COD and BOD results was reliable. Both BOD and COD results, when compared with Table 7, showing common wastewater quality results, can be seen to be high. The mean stickwater COD value was approximately 300 times higher than strong domestic wastewater. This indicated that the stickwater would add a considerable oxygen requirement loading, if it was discharged to the recipient. Care should however be taken in interpreting this result, because the stickwater was produced intermittently as a batch process, whereas the contaminant concentrations in Table 7 refer to continuous flow operation. The total mass flow of contaminants from a batch operation will therefore be lower than that from a continuous flow system.

Figure 12: Variations in stickwater quality resulting from a range of *offcuts* inputs









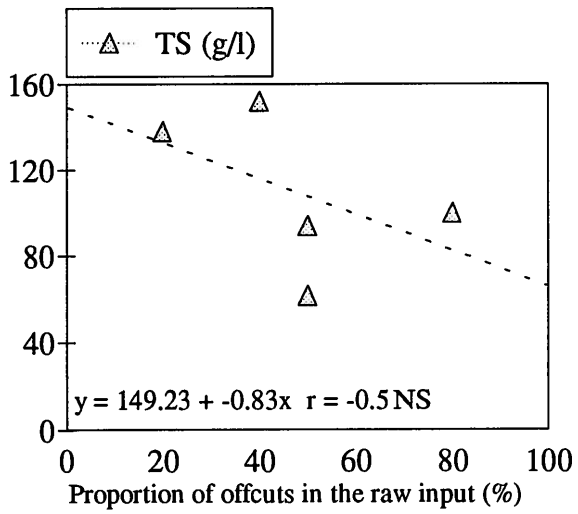
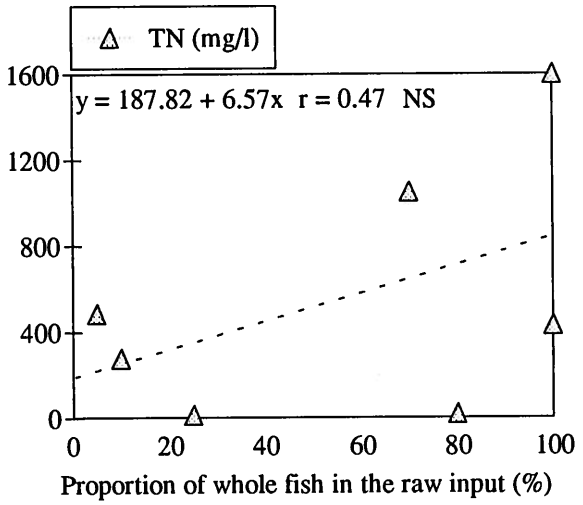
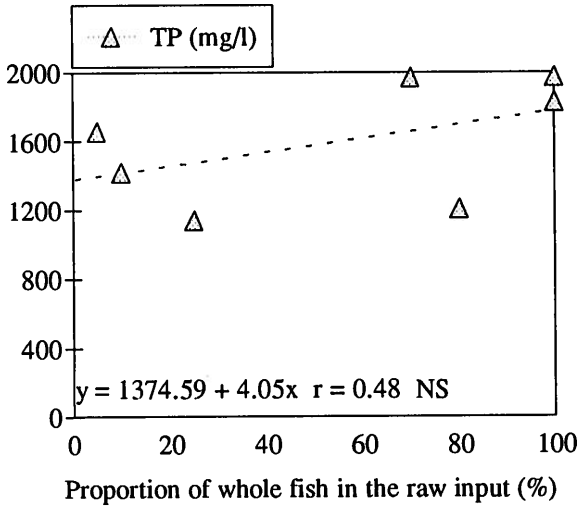
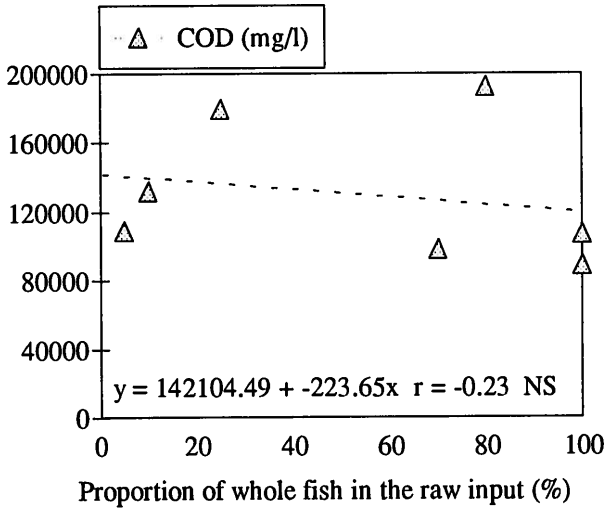
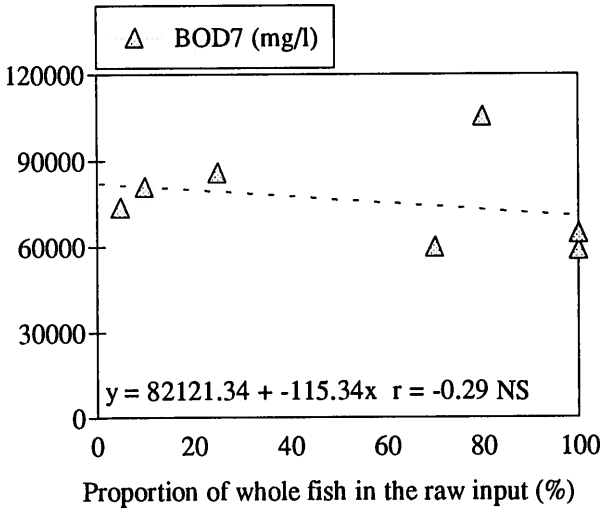


Figure 13: Variations in stickwater quality resulting from a range of *whole fish* inputs









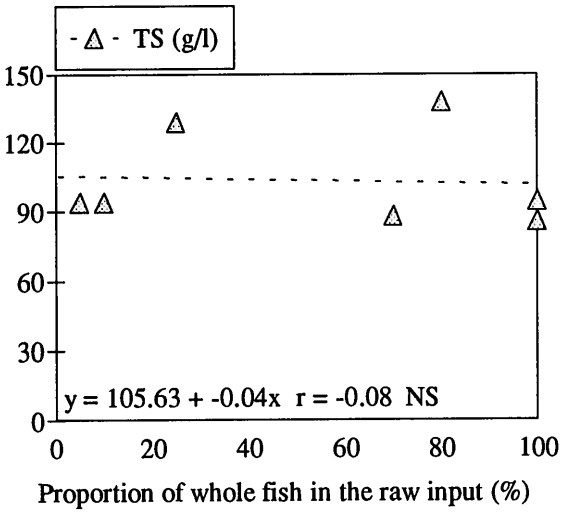
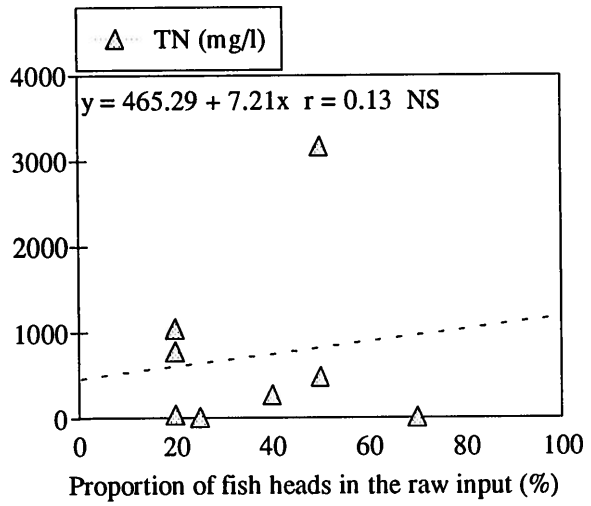
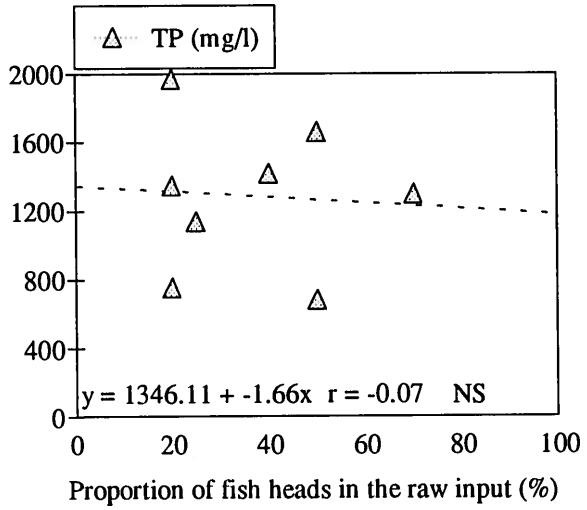
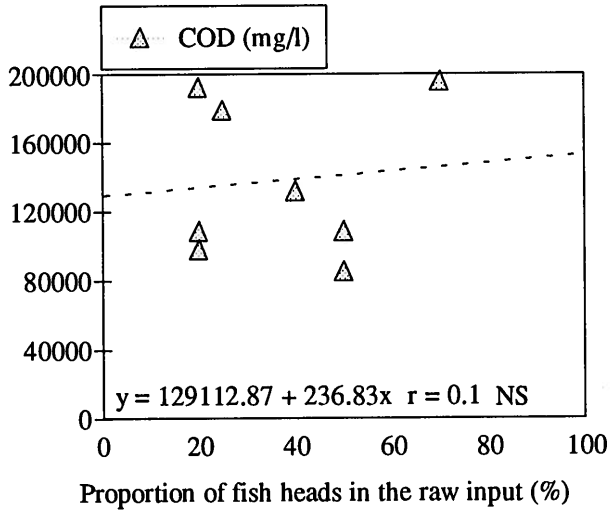
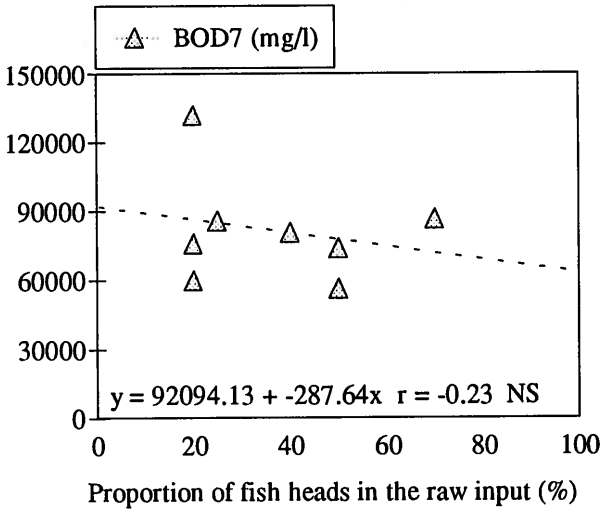


Figure 14: Variations in stickwater quality resulting from a range of *fish head* inputs









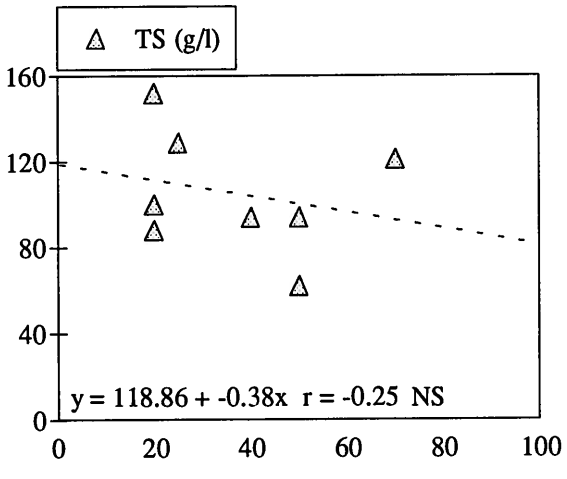


Table 7: Domestic and industrial wastewater contaminant concentrations (adapted from Cripps, in press).

Source	Facility	TS (mg/l)	TP (µg/l)	TN (mg/l)	COD (mg/l)	BOD (mg/l)
Various	Aquaculture	14	125	1.4	-	8
Tchobanoglous & Burton (1991)	Domestic wastewater					
	weak					
	medium	350	4000	20	250	110
	strong	720	8000	40	500	220
		1200	15000	85	1000	400
Henry & Heinke (1989)	stormwater runoff	170	350	3.5	100	14
Degrémont (1973)	Paper pulp mill	-	-	-	-	1800
Henry & Heinke (1989)	Meat processing	300	-	3	-	640

Because of the variability in the daily production of raw material and its batch processing, it is more useful to relate the environmental loading to the unit volume of raw material to be treated, rather than to an estimated daily production volume. Using typical values for the daily production per person of certain contaminants (Henry and Heinke, 1989), it is possible to calculate the number of people per day which would produce an equivalent waste loading: population equivalent (PE).

For 100 % viscera:

$$\frac{Vs/b \,.\, BOD}{Vr/b \,.\, PE} = \frac{255\,l \,.\, 81{,}767\ mg/l}{610\,l \,.\, 76000\ mg/person.day}$$

$$= 0.45\ people.days/kg\ raw\ viscera$$

1 tonne viscera $\Rightarrow$ 450 people.days

where: Vs = volume of stickwater produced per batch
Vr = volume of raw material treated per batch
b = batch

For 100 % whole fish:

$$\frac{Vs/b \,.\, BOD}{Vr/b \,.\, PE} = \frac{143\,l \,.\, 64{,}667\ mg/l}{650\,l \,.\, 76000\ mg/person.day}$$

$$= 0.19\ people.days/kg\ raw\ whole\ fish$$

1 tonne whole fish $\Rightarrow$ 187 people.days

One tonne of raw viscera, or whole fish, can therefore be expected to produce the equivalent BOD loading that 450, or 197 people respectively, produce in one day. This is a significant oxygen requirement if released into the recipient, and refers only to one of the 3 phases produced by the separator.

The quantity of TS in the stickwater can be seen to be on average considerably higher than even strong domestic wastewater. PE values, calculated as above, using a per capita TS contribution figure of 90 g/day (Henry and Heinke, 1989), can be used to illustrate the loading. One tonne of raw viscera or whole fish can therefore be expected to produce the equivalent TS loading that 553 or 232 people respectively produce in one day. This is also a significant quantity of solids if returned to the recipient. Such a quantity would be expected to cause several environmental effects including, smothering of endemic organisms, changes in the benthic fauna diversity and biomass, and reductions in plant species due to light restrictions in the vicinity of the outfall.

The TN results must be treated with caution. Both the great range and the minimum values obtained, indicate that these results are suspect. The lower end of the range, approaching 1 mg/l is lower even than values expected for extremely dilute aquaculture wastewaters (Table 7). Two explanations may account for these low values. Firstly the separator may have been highly efficient at removing protein (which comprises a major part of the TN) and placing it in the solid fraction. Alternatively, the analytical method used to determine the TN concentration may have been inadequate. A simple mass flow calculation indicates that the second explanation is the more likely. Of a TS content of 9,500 g/l, approximately 3331 mg/l (533 mg TN/l . 6.25 Kjeldahl N constant) was mainly of organic origin, i.e. protein. This leaves an unrealistically large quantity of 6,169 mg TS/l of primarily inorganic material and fats.

The suspected error may have occurred because after sampling, the stored stickwater separated into two fractions. A gelatine type substance, which would contain high TN concentrations, floated at the surface of the liquid. Prior to analysis, a representative sample should have been obtained by re-dissolving this gelatine. This sub-sample homogenisation may not have been adequate. Future studies should take care to avoid this methodological error.

TP concentrations were lower than that expected in weak domestic wastewater. The majority of this P will have originated in bones. Whilst the TP inputs shown above were adequate to cause an environmental impact, particularly in regions in which primary production is limited by insufficient available P, this contaminant is of less importance than the large oxygen demands described earlier.

Overall, it was then evident that significant impacts would have been expected from the stickwater fraction, had it been discharched into the recipient at the slaughtery studied. The demand for oxygen and the quantity of solids resulting were particularly serious. Should stickwater be discharged in the future, these parameters would require close monitoring. The operational strategy used at this slaughtery, i.e. the recombination of the stickwater into the separated solid fraction did however, not just reduce the impacts from this source, but eliminated them completely. The results described above indicate that recombination is, from an environmental standpoint, a highly successful strategy.

More work would be required to reliably predict and model the general environmental efficacy of the process, as applied to other locations and management regimes, with respect to varying input components and local conditions. Differences in farmed fish feed, and in slaughtery techniques, for example, would be expected to produce different concentrations of the environmental parameters measured in this study. The treatment process does however appear suitable for a wide geographical range of slaughteries which at present have no, or little, means of treating solid wastes.

The nutritional aspects of the stickwater have not been investigated. This phase, which is mixed in with the solid phase to form a viscous product, is well suited to the manufacturing process of a local pig feed producer. Hence the stickwater comprises a part of the usable by-

product. It also contains some protein, and its addition to the nutritional value of the grax would be of interest.

As stated above, the stickwater fraction, if left to cool, rapidly forms a strong gel. This may indicate a high gelatine content. No efforts have been made to determine this content, or to identify the potential uses of fish gelatine.

8.3. Oil-fraction

During the last decade the nutritional benefits of fish oils have received great attention. This has increased the interest in marine fish oils. Cod-liver oil has been the traditional fish oil product for consumer use. Now, several fish oil products are marketed in various forms.

No commercially available salmon oil is thought to be currently on the market. The oil produced in this separation process has a high quality due to the fresh raw materials and the thermally gentle process (short exposure to high temperatures), and hence it could be of considerable commercial interest.

Analyses performed on samples prior to this experiment revealed excellent freshness parameters - 0 % free fatty acids, and negligible rancidity parameters. Hence these parameters were not included in these tests.

8.3.1. Results

Two tests were conducted on three replicate samples of pure raw materials - whole salmon (downgraded) and viscera. The result from these tests are presented in Table 8.

Table 8: Fatty acid composition of salmon oils obtained from whole salmon and viscera (3 replicates)

Sample number		*6*		*7*	
Raw material					
Whole salmon (%)		100		0	
Viscera (%)		0		100	
Oil fraction					
Fatty acid composition		Mean	sd	Mean	sd
Saturated		19.00	0.14	20.43	0.12
	C14:0	5.53	0.09	5.73	0.05
	C16:0	11.53	0.09	12.33	0.09
	C18:0	1.93	0.05	2.37	0.05
Monosaturated		50.99	0.29	43.60	0.28
	C16:1	6.63	0.09	6.57	0.05
	C18:1	16.60	0.08	16.23	0.05
	C20:1	15.67	0.12	11.27	0.52
	C22:1	12.17	0.19	9.93	0.33
Polyunsaturated (n-3)		19.93	0.17	25.11	0.26
	C18:3	0.84	0.02	0.92	0.02
	C18:4	2.57	0.05	2.63	0.05
	C20:3	0.13	0.00	0.12	0.00
	C20:4	1.50	0.00	1.63	0.05
	C20:5	5.37	0.05	7.03	0.24
	C21:5	0.37	0.00	0.45	0.01
	C22:5	1.87	0.09	2.73	0.09
	C22:6	7.23	0.12	9.27	0.26
Polyunsaturated (n-6)		3.39	0.12	3.28	0.04
	C18:2	2.47	0.09	2.27	0.05
	C20:2	0.36	0.01	0.33	0.00
	C20:3	0.13	0.00	0.15	0.00
	C20:4	0.33	0.01	0.43	0.02
	C22:5	0.10	0.01	0.11	0.00

The results from the various experiments carried out with different raw material combinations are presented in Table 9.

Table 9: Fatty acid composition of salmon oils obtained from different raw materials.

Sample number	*1A*	*1B*	*2A*	*2B*	*2C*	*2D*	*3A*	*3B*	*3C*	*4A*	*4B*	*4C*	*5A*	*5B*
Raw material														
Whole fish (%)	100		10		100*		80	70				25	5	
Heads (%)		50	40	20		20		20		70		25	50	
Viscera (%)									100		100			100
Backbone - Frame (%)												25		
Offcuts (%)		50	50	80		40	20							
Skin (%)						40				30		25	45	
Saithe (%)								10						
Oil fraction														
Fatty acid composition														
Saturated	21.6	22.5	22.9	22.5	19.6	20.5	20.2	19.6	18.4	18.6	19.2	18.9	18.4	21.0
C14:0	5.5	5.9	6.0	5.8	5.2	5.4	5.5	5.4	5.5	5.4	5.4	5.3	5.4	5.9
C16:0	13.7	14.3	14.5	14.3	12.0	12.7	12.5	12.0	11.0	11.3	11.6	11.5	11.0	12.7
C18:0	2.4	2.3	2.4	2.4	2.4	2.4	2.2	2.2	1.9	1.9	2.2	2.1	2.0	2.4
Monosaturated	43.7	44.3	44.2	45.0	45.0	42.9	46.1	48.4	51.8	51.8	46.4	48.7	49.7	45.2
C16:1	6.8	6.7	6.9	6.7	6.3	6.4	6.1	6.1	7.0	6.9	6.9	6.7	6.9	6.6
C18:1	17.7	17.2	17.8	19.5	16.9	16.4	16.8	17.0	17.3	17.1	16.8	16.8	17.1	16.5
C20:1	10.7	11.1	10.4	10.2	12.0	11.0	12.4	13.9	15.7	15.8	12.4	14.0	14.3	11.9
C22:1	8.5	9.3	9.1	8.6	9.8	9.1	10.8	11.4	11.8	12.0	10.3	11.2	11.4	10.2
Polyunsaturated (n-3)	25.0	24.0	23.7	22.8	24.4	24.8	22.7	21.5	19.9	19.7	23.7	22.0	21.8	23.0
C18:3	0.83	0.76	0.72	0.74	0.94	1.00	1.00	0.96	0.85	0.84	0.90	0.87	0.89	0.87
C18:4	2.1	2.0	2.0	1.8	2.1	2.3	2.4	2.8	2.6	2.4	2.5	2.4	2.7	2.5
C20:3	0.10	0.11	0.09	0.09	0.14	0.13	0.13	0.12	0.13	0.12	0.13	0.13	0.12	0.11
C20:4	1.3	1.2	1.2	1.2	1.5	1.5	1.4	1.2	1.5	1.5	1.6	1.5	1.6	1.5
C20:5	7.7	7.3	7.3	6.9	6.9	7.4	6.2	5.8	5.3	5.4	6.9	6.2	6.0	6.7
C21:5	0.36	0.31	0.32	0.30	0.42	0.41	0.39	0.37	0.39	0.37	0.45	0.41	0.41	0.44
C22:5	2.5	2.3	2.3	2.3	2.8	2.4	2.2	1.7	2.0	1.9	2.6	2.3	2.2	2.5
C22:6	10.1	10.0	9.8	9.5	9.6	9.7	9.0	8.5	7.1	7.2	8.6	8.2	7.9	8.4
Polyunsaturated (n-6)	3.5	3.2	2.9	3.3	3.9	3.7	3.8	3.5	3.4	3.3	3.4	3.4	3.5	3.3
C18:2	2.7	2.4	2.2	2.5	2.8	2.7	2.8	2.6	2.5	2.4	2.4	2.4	2.5	2.3
C20:2	0.28	0.27	0.24	0.25	0.37	0.36	0.36	0.34	0.36	0.36	0.34	0.35	0.35	0.34
C20:3	0.11	0.11	0.10	0.11	0.16	0.14	0.14	0.12	0.14	0.13	0.15	0.15	0.14	0.15
C20:4	0.37	0.35	0.33	0.33	0.48	0.44	0.41	0.37	0.33	0.32	0.41	0.38	0.36	0.41
C22:5	0.08	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.09	0.10	0.10	0.10	0.11

Presumed value - not found on the sample report forms

8.3.2. Discussion

As mentioned previously, the differences in composition between whole fish and viscera produce different outflow phase quantities. Due to the tissue structure and lower fat content, whole fish generated only 10 % of the amount of oil that was generated by viscera.

The fatty acid composition, however, does not differ greatly. The largest differences can be seen in the monosaturated and polyunsaturated (n-3) fractions (Tables 8 and 9). Whole fish generated oil with more mono-unsaturated fatty acids (C20:1 and C22:1), whereas oil originating from viscera contained a higher proportion of n-3 polyunsaturated fatty acids, especially the nutritionally important C20:5 eicosapentaenoic acid (EPA) and C22:6 docohexaenoic acid (DHA).

The content of these fatty acids in the salmon oil was compared with the content in wild salmon and in other commercial fish oils (Table 10 and Figure 15).

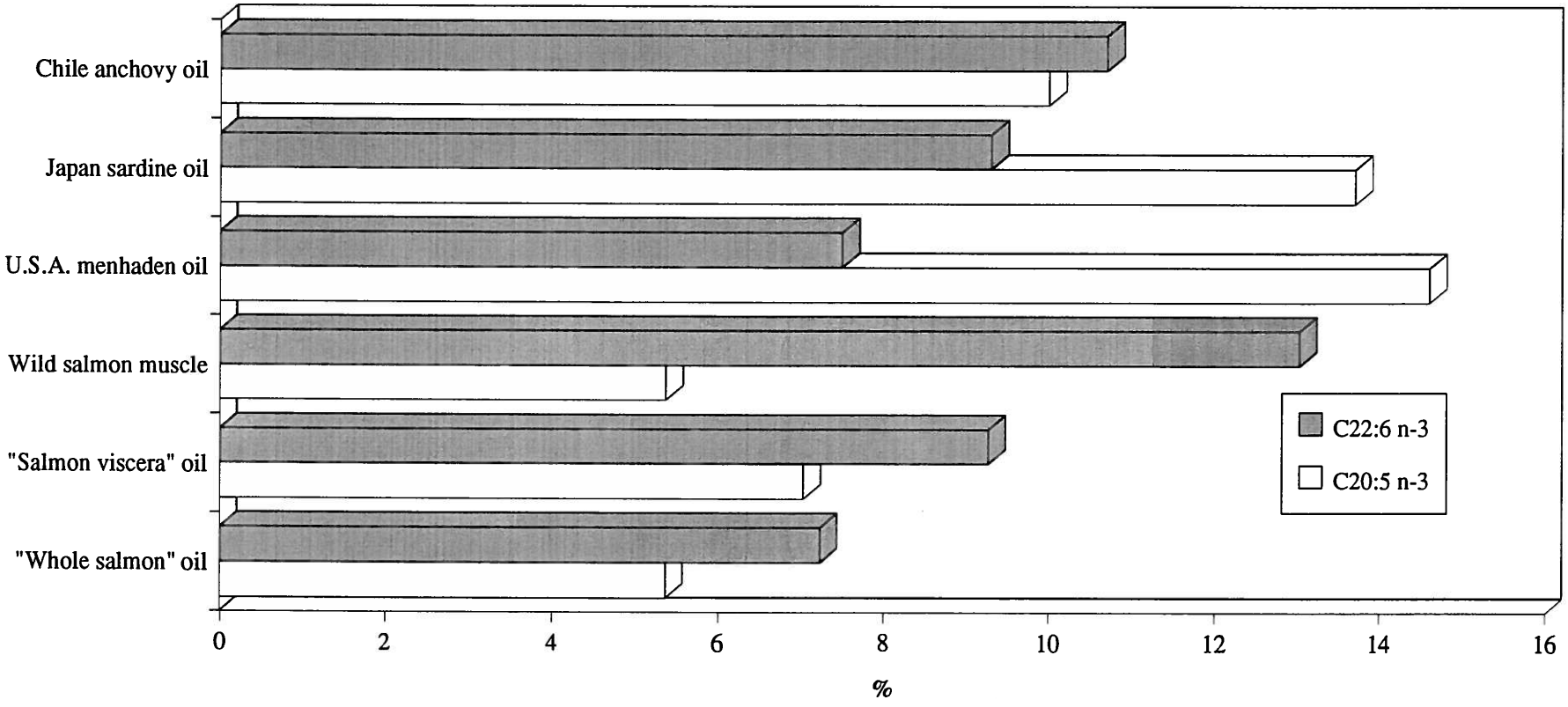
Table 10. Content of n-3 polyunsaturated fatty acids in different salmon oils derived from waste compared to the content in wild salmon and to some non tropical commercial fish oils.

Fatty acid composition **Origin**	Whole salmon	Salmon viscera	Wild Salmon [a]	U.S.A. Menhaden [b]	Japan Sardine[c]	Chile Anchovy[d]
Eicosapentaenoic acid C20:5 n-3	5,37	7,03	5.37	14,6	13,7	10,0
Docosahexaenoic acid C22:6 n-3	7,23	9,27	13.03	7,5	9,3	10,7

a Salmon salar (Cronin et al., 1991)
b Chesapeake Brevoortia tyrannis (Ackman, 1982)
c Sardinops melanosticta (Itabashi and Tahagi, 1980)
d Eugraulis ringens (Ackman, 1990)

Unfortunately the analyses of the fatty acid composition of the raw material was not included in this project. Hence it is impossible to estimate potential loss of the rather unstable n-3 polyunsaturated fatty acids in the separation process. Table 10, however, includes the content of EPA and DHA in the lipid fraction of wild salmon. Compared to these data, it is evident that the oil produced in these experiments is lower in DHA than wild salmon, whereas the content of EPA is comparable.
From Table 10 and Figure 15 it can further be seen that the salmon oils contain a significantly lower in EPA concentration than the commercial fish oils mentioned in Table 10, whereas the content of DHA is comparable.
The fatty acid composition, however, is highly dependant on the fish diet (Waagbø et al., 1993). A high content of unsaturated fatty acids in the diet, yields a correspondingly high fraction in the salmon muscle. Hence the presented values could differ significantly with different feed. A further examination of these aspects is however beyond the scope of this experiment. The quality aspects of the oil require further examination with respect to the raw materials, process parameters and storage stability.

Figure 15: Concentration of n-3 polyunsaturated fatty acid in different salmon oils derived from waste, wild salmon muscle and some non-tropical commercial fish oils



9. Summary of conclusions

1. The three-phase separator, as used in this study, effectively solved the environmental impact problems resulting from solid waste from this salmon slaughtery.
2. Recombination of the stickwater into the solid phase, as opposed to direct discharge to the recipient eradicated the environmental loading from the stickwater phase and as such can be considered an environmentally sound policy.
3. This recombined solid/stickwater phase was well suited as a protein source in pig feed, because of its high protein quality and low (<5 %) fat content.
4. The environmental loading from the stickwater phase, as estimated using COD, BOD7, TS, TN and TP was great but intermittent. 1 t of viscera produced a BOD population equivalent of 450 people.days and 1 t of whole fish produced a population equivalent of 187 people.days. TS loadings were higher.
5. In the oil phase, the salmon oil was relatively high in n-3 polyunsaturated fatty acids, very fresh (not rancid) and probably well suited for human consumption and or usage.
6. More work is required to further optimise and document the process. Aspects of key interest are: environmental impact of specific raw material sources and storage stability.
7. Care must be taken to fully homogenise samples prior to sub-sampling for analysis of the environmental parameters.

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