VALUE-ADDING TO SEAFOOD, AQUATIC AND FISHERIES WASTE THROUGH AQUAFEED DEVELOPMENT

Fiona. M. Gavine, Rasanthi. M. Gunasekera, Geoff. J. Gooley and Sena. S. De Silva

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Title: **Value-adding to seafood, aquatic and fisheries waste through aquafeed development.**

Authors: **Fiona. M. Gavine, Rasanthi. M. Gunasekera, Geoff. J. Gooley and Sena. S. De Silva.**

Address: **Marine and Freshwater Resources Institute, Snobs Creek**
Private Bag 20
Alexandra 3714
Victoria

Tel: (03) 5774 2208
Fax: (03) 5774 2659

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1 NON-TECHNICAL SUMMARY

99/424	**Value-adding to seafood, aquatic and fisheries waste through aquafeed development.**

Principal Investigator: Geoff Gooley

Co-Investigator: Sena De Silva

Address: Marine and Freshwater Resources Institute
Snobs Creek
Private Bag 20
Alexandra
Victoria 3714
Telephone: 03 5774 2208 Fax: 03 5774 2659

Objectives:

1. To undertake an audit of seafood, fisheries and other aquatic "waste" biomass within Victorian industry to characterise the availability and condition of such resources with potential for utilisation within relatively low-cost, semi-refined compound aquafeed development.
2. To undertake an analysis of nutritional condition of selected waste resources with potential for utilisation in such aquafeeds.
3. To undertake digestibility trials with commonly cultured species of waste products which appear to have potential for inclusion in aquafeeds.

Key Results:

- The industry audit showed that there is a significant quantity of seafood processing, food processing and aquatic waste in Victoria available for value-adding or further processing.
- The suitability of these wastes for inclusion in fish diets was evaluated based on their chemical composition.
- The results demonstrated that those most suitable for use as a fishmeal replacement in aquafeeds were those that contained a high proportion of finfish (including shark) wastes. The potential for by-catch as a source of raw product was highlighted as a significant opportunity.
- The study emphasised the need for a multi-pronged approach to determining the suitability of ingredients for fish diets. In all cases, the findings must be confirmed through growth trials and a thorough assessment of technical and economic feasibility.

Non Technical Summary

The management and disposal of solid wastes from seafood processing, food manufacturing and allied industries is a major economic and environmental issue for Australian industry. Large quantities of wet waste of this nature are routinely disposed of to landfill at considerable cost to industry. Some companies have developed markets or alternative uses for their wastes (such as petfood, bait, pig food or fertilisers) to avoid or offset the costs of disposal, but generally the wastes are supplied free of charge to secondary users and there is limited opportunity for downstream value-adding.

The utilisation of seafood, aquatic and other food processing wastes as a replacement for imported fishmeal in aquafeed production is the main focus of this project. The availability of locally-produced formulated feeds using these otherwise wasted resources would provide a firm base to underpin current and future aquaculture production in Victoria and indeed Australia.

The industry audit showed that a significant quantity of processing waste, particularly finfish and shark frames and viscera, was produced in the Melbourne-Geelong area (4,100 tonnes). In addition, discussions with processors at the Melbourne Wholesale Fish Market have indicated that the quantity of waste collected there (2,000-2,500 tonnes per annum) could be doubled if small processors were encouraged to return their wastes. The quantities of wastes available in Lakes Entrance, Portland and inland are considerably smaller (160-780 tonnes per annum), but the number of fishing ports in the Lakes Entrance and Portland area would offer scope for the utilisation of bycatch in any processing plant that was set up. In addition to seafood processors, wastes from several different industries were investigated for their potential use in aquafeeds. Petfood processing wastes from one large plant in Victoria produces 3,250 tonnes of process waste per annum and an additional 11,000 tonnes of activated sludge. The dairy processing industry produces solid wastes from most of its processing plants in the form of filter cake, one plant alone produced 60 tonnes per annum of this waste. Specialised dairy plants also produce pure casein, with one plant of this type producing 141 tonnes per annum.

A series of chemical analyses were carried out on selected waste products, including the proximate composition (moisture, protein, total lipid, and ash content), amino acid and fatty acid composition. The composition of the samples was compared with Chilean fishmeal and the whole body tissue of three cultured fish species (Rainbow trout, Murray cod and Australian shortfin eel). The latter data were used for comparison of the wastes to the nutrient requirements of fish species through indices such as A/E ratio and essential amino

acid index (EAAI).

The results of the sample analysis demonstrated that although a number of the samples had potential for use in aquafeeds, the wastes most suitable for use as a fishmeal replacement were those which contained a high proportion of finfish wastes. Other samples had potential for incorporation into feeds as mineral supplements or additives.

The study emphasised the need for a multi-pronged approach to determine the suitability of ingredients for incorporation into fish diets. In all cases, the findings have to be confirmed through growth trials, prior to possible commercialisation.

The economic feasibility of the concept of utilising seafood processing waste for aquafeed relates to the market for aquafeed in Australia, the reliability of supply of the wastes, price for fish meal world-wide and the cost of technology/ plant to process the waste. Other considerations include the shelf-life, effects on palatability and many other criteria which need to be taken into account when a new ingredient is to be incorporated into a feed.

KEYWORDS: Fishmeal replacement; aquafeeds; seafood processing wastes.

Fishing boat returning

Melbourne wholesale fish market

Processing line

Marine processing waste

FINAL REPORT

99/424 Value-adding to seafood, aquatic and fisheries waste through aquafeed development.

2 Background

The management and disposal of solid wastes from seafood processing, food manufacturing and allied industries is a major economic and environmental issue for Victorian industry. Large quantities of wet waste of this nature are routinely disposed of to landfill at considerable cost to industry. Some companies have developed markets or alternative uses for their wastes (such as petfood, bait, pig food or fertilisers) to avoid or offset the costs of disposal, but generally the wastes are supplied free of charge to secondary users and there is limited opportunity for downstream value-adding. The landfill disposal option is becoming increasingly expensive with seafood processing waste classified as "prescribed putresible/ organic" waste and attracting a premium disposal charge. In addition, the Victorian EPA imposes a levy per tonne for the dumping of wastes to landfill and is working to encourage companies to move away from such practices.

In December 2000, the Victorian Government released an Industrial Waste Management Policy (Prescribed Industrial Waste) which aimed to encourage Victorian industry to reuse, recycle and recover energy from prescribed wastes and manage these wastes to retain and realise its full economic value. The policy also encouraged companies to recognise the social, environmental and economic costs of poor waste management practices (Victoria Government Gazette, No. S183, Tuesday 5 December, 2000).

The volume of waste currently generated by the seafood processing and allied industries in Victoria is significant by any standards. A preliminary survey of a small number of companies conducted prior to this project gave an insight into the variety and magnitude of wastes generated in Victoria, *e.g.*:

- 350-500 tonnes shark waste.
- 600 tonnes flathead frames and viscera.
- 3-500 m^3 of scallop shells and viscera.
- 200 tonnes per annum trout frames and viscera.
- 1000 tonnes of wet plankton biomass.

The cost of disposal varied greatly between individual companies depending on the quantity and type of waste and the method of disposal, but some companies paid $30,000-$50,000 per annum to have their wastes collected and disposed of by a contracted waste management company. It is thought that the total waste disposal costs for the Victorian seafood processing industry are in the order of several hundreds of thousands of dollars annually.

3 Need

The present study aimed to evaluate the extent of the waste resource in Victoria by identifying companies producing significant quantities of waste through a detailed industry audit. Selected samples of waste were initially analysed for protein, lipid and ash content and subsequently analysed for amino acid and fatty acid content. The potential of selected waste products for utilisation in aquaculture feed ("aquafeed") production was determined by comparing the components of the waste to fishmeal and selected fish species so that the potential of the waste as a low-cost alternative to fishmeal in compound pelleted aquafeeds could be evaluated.

The aquaculture industry is the fastest growing rural sector in Australia and has the potential to contribute significantly to the domestic economy and export earnings of all states. In 1998/99, the total production of the aquaculture industry in Australia was 32,400 tonnes worth an estimated $614 million to the economy at the farm gate (O' Sullivan and Dobson, 2000). This has increased from 11,900 tonnes with a value of $135.9 million in 1988/1989. In 1998 about 6,000 people were employed in the aquaculture sector and the industry contributes significantly to regional employment around Australia.

The Australian aquaculture industry is dominated by the culture of high-value carnivorous finfish (such as salmon, trout, silver perch, barramundi and tuna) and filter-feeding molluscs, particularly mussels and oysters. In 1998/99, 18,421 tonnes of finfish were cultured in Australia, with a value of $274 million. The current production and future development of the finfish aquaculture industry in Australia is primarily dependent on the availability of cost-effective formulated aquafeeds, which in practice are a major cost item and can contribute up to 50% of the total operating costs of a fish farm (Williams, 1998). Formulated aquafeeds usually contain imported fishmeal as an essential ingredient and the global fishmeal market primarily determines the price at which aquafeeds are availabile to the fish farmer.

It is widely accepted that, given the extensive natural resource base of Australia and the decline of marine capture fisheries world-wide, the aquaculture industry in Australia will continue to expand in the future. Irrespective of technological advances in fish genetics and husbandry, increased production in the aquaculture industry can only be achieved through proper nutrition (De Silva, 1999), *i.e.* the availability of nutritionally balanced, cost-effective diets. To maintain the current level of aquaculture expansion both in Australia and world-wide, there is a clear need therefore to reduce the aquafeed industry's dependence on wild-caught fish meal supplies. This is particularly relevant to Australia due to the industry's reliance on imported fishmeal (Williams, 1998).

Recent studies by Food Science Australia have investigated the use of trout offal to make extruded trout diets (George, 2000; Ingram, 1999). The study showed that trout or salmon wastes could be successfully converted into feeding pellets for trout or other farmed fish. The fish fed on the recycled diet grew at the same rate as those on the control diet although Food Conversion Rates (FCRs) were not quite as good.

4 Objectives

The utilisation of seafood, aquatic and other food processing wastes as a replacement for imported fishmeal in aquafeed production is the main focus of this project. The availability of locally-produced formulated feeds utilising these otherwise wasted resources would provide a firm base to underpin current and future aquaculture production in Victoria. The specific objectives of the project may be summarised as follows:

1. To undertake an audit of seafood, fisheries and other aquatic "waste" biomass within Victorian industry to characterise the availability and condition of such resources with potential for utilisation within relatively low-cost, semi-refined compound aquafeed development.
2. To undertake an analysis of nutritional condition of selected waste resources with potential for utilisation in such aquafeeds.
3. To undertake digestibility trials with commonly cultured species of waste products which appear to have potential for inclusion in aquafeeds.

The lead agency in project implementation was the Marine and Freshwater Resources Institute (Snobs Creek), which conducted the industry audit and collected samples for analysis. Deakin University as an associate agency undertook sample analysis and conducted digestibility trials with selected fish species.

5 Materials and Methods

5.1 Industry Audit

The Melbourne Wholesale Fish Market (MWFM) dominates the post-harvest seafood industry in Victoria and information on the structure and organisation of the market was sourced through various recent reports (Read Sturgess, 1995, 1997; Victorian Fisheries, 1995). This information was cross-checked for up-to-date accuracy with the MWFM (Tim Rienets, pers. comm.).

In addition to the MWFM, other seafood processors were identified by a search of the Victorian Yellow Pages as there appears to be no accessible central database of the companies involved in seafood processing in Victoria. A questionnaire was designed for standardised collection of data. The industry audit was conducted by personal interview, telephone and fax.

5.2 Sample Selection and Collection

Samples were collected from a diverse range of processors to assess suitability for use in aquafeeds (Table 5.1). In most cases, two batches of sample were collected approximately five months apart so that batch-to batch variability could be assessed. After collection, samples were placed on ice in a portable cooler and returned to the laboratory where they were frozen prior to analysis.

Table 5.1 Samples submitted for proximate analysis at Deakin University.

Company	Sample	ID Code	Date of Collection	
			Batch 1	Batch 2
Goulburn River Trout	Trout offal	TO	28/02/2000	2/8/2000
Austrimi Seafoods	Fish processing wastes	SFW	8/03/2000	14/8/2000
K & C Fisheries, Sale	Carp roe	CR	3/03/2000	8/8/2000
	Carp frames and viscera	CO	3/03/2000	8/8/2000
Lakes Entrance Fisheries Co-operative	Fish frames	FF2	3/03/2000	8/8/2000
A & S Katos and Sons	Scallop waste	SG	8/03/2000	14/8/2000
Allfresh Seafoods	Fish frames	FF1	8/03/2000	14/8/2000
	Fish viscera	FV	8/03/2000	14/8/2000
Uncle Bens Australia	Catfood waste	CFW	2/03/2000	
	Bone meal waste	BMW		9/8/2000
	Dog food waste	DFW		9/8/2000
	General waste	GW	2/03/2000	
Zootech	Plankton	ZP	8/03/2000	14/8/2000
Bonlac Foods	Toora – Casein	DW1		8/8/2000
	Codben – Filter waste	DW2		14/8/2000

5.3 Chemical Analysis Of Selected Waste Samples

A series of chemical analyses were carried out on the waste products, including the proximate (moisture, protein, total lipid, and ash content), amino acid and fatty acid composition. These analyses were complimented by comparison with fishmeal (Chilean origin) and whole body tissue of three cultured fish species, *viz*. rainbow trout (*Oncorhynchus mykiss*), Murray cod (*Maccullochella peelii peelii*) and Australian shortfin eel (*Anguilla australis*). The latter data were used to determine how closely the ingredients conformed to the nutrient requirements of fish species, through the use of indices such as amino acid (A/E) ratio and essential amino acid index (EAAI), see Section 5.3.5 for further details.

The waste samples were thawed on arrival at the laboratory and moisture content was subsequently determined by drying the samples to constant weight in an oven at 60°C. The dried samples were finely ground prior to analysis of proximate composition, amino acid and fatty acid composition and selected mineral elements. A sample of Chilean fishmeal (from Ridley Pty. Ltd., NSW) was treated similarly and also analysed for comparison. In addition, whole body tissue amino acid composition was determined on farm-reared Australian shortfin eel, Murray cod and rainbow trout. A minimum of six individuals of each species was snap frozen, ground and sub-sampled for the analysis. Chemical analysis was based on dry ingredients as it was thought unlikely that the aquafeed industry would use these ingredients in the raw form.

5.3.1 Proximate analysis

A minimum of three aliquots of dried material of industry waste and fish meal (Chilean origin) were used for proximate, amino acid, fatty acid and selected mineral element analyses, according to the following methods:

- Proximate composition analysis was conducted using standard methods (AOAC, 1990);
- Protein by estimating total nitrogen (protein=6.25 x total nitrogen) using an automated Kjeltec Model 2300 (Foss Tecator, Sweden);
- Lipid by chloroform: methanol (2:1) extraction (Folch *et al.*, 1957); and
- Ash by burning in a muffle furnace at 550°C for 18 h.

All analyses were conducted in triplicate on each aliquot.

5.3.2 Amino acid analysis

The method used for amino acid analysis has been previously described (Gunasekera *et al*., 1998, 1999; Gunasekera and De Silva, 2000). The samples were hydrolysed for 24h at

100°C with 6N HCl in sealed glass tubes replaced with nitrogen. An aliquot of an appropriate amount of the hydrolysate was taken, diluted with 0.25 M borate buffer, pH adjusted to 8.5 and filtered through a 25 μm membrane filter.

The pH adjusted samples were reacted with 9-fluroenylmethyl chloroformate (FMOC) to form amino acid FMOC derivatives using an automated GBC LC 1610 Autosampler, with a Hypersil column (150 mm length x 4.6 mm in internal diameter). L-hydroxyproline was used as an internal standard and the amino acids were analysed by pre-column fluorescence derivative method using a fully automated, GBC LC 1150 HPLC (GBC Scientific Equipment, Australia). Resulting peaks were analysed using a Winchrom software package (GBC Scientific Equipment, Australia). Tryptophan was not estimated in this study.

5.3.3 Fatty acid analysis

Fatty acid analysis was also carried out according to previously described methods (De Silva *et al.*, 2001). The samples were homogenised in chloroform: methanol (2:1) using a Ika-Labortechnik Ultra-Turrax T8 homogeniser and total lipid was extracted and estimated gravimetrically (Folch *et al.*, 1957). The fatty acids in the total lipid were esterified into methyl esters by saponification with 0.5 N methanolic NaOH and trans-esterified with 14 % BF_3 (w/v) in methanol (AOAC, 1990). Three aliquots of each esterified sample (fatty acid methyl esters) were analysed in a Shimadzu GC 17A, equipped with an Omegawax 250 capillary column (30m L x 0.32mm internal diameter), a FID detector and a split injection system (split ratio 50:1). The carrier gas was helium and injector port and detector temperatures were 240°C and 250°C, respectively. The temperature program was 190°C for 5 min, 190-240^{o}C at 2^{o}C min^{-1}, and held at 240^{o}C for 10 min. Fatty acids were identified relative to known external standards and the resulting peaks were quantified using C23:0 as an internal standard (Sigma, USA).

5.3.4 Mineral analysis

The calcium, copper, potassium, iron, zinc and phosphorous content of fish samples and industry waste samples were also determined. These inorganic constituents were determined after decomposing samples using a closed vessel nitric acid digestion technique (AOAC, 1990). Essentially, 0.2 g of sample and 10.0 mL of nitric acid (AristaR, BDH) were added to 70 mL teflon-lined steel bombs, which were placed in an oven at 150^{o}C for 3h. After cooling, the contents of the bombs were transferred to 25 mL volumetric flasks. Blanks and certified reference materials (NIST Bovine Liver 1577b, NRC Dogfish Muscle DORM-2, and APG Minerals Solution, Order 4873 Lot 18738) were also digested and analysed to test for contamination and recoveries. Recoveries were always within 15% of the certified value, when the resulting concentrations were within the analytical range of the detection method.

After digestion, Ca, Cu, Fe, K and Zn were determined after appropriate dilution using flame atomic absorption spectrophotometry (APHA, 1998). Calibration standards were prepared from 1.00 g L^{-1} stock solutions of the metals (Spectrosol, BDH Chemicals). P was determined after appropriate dilution using the ascorbic acid (molybdenum blue) method (APHA, 1998). For all analyses AnalaR Grade purity reagents were used.

5.3.5 Amino Acid (A/E) Ratio and Essential Amino Acid Index (EAAI)

The A/E ratio is essentially a measure of the proportion of an individual essential amino acid (EAA) to total essential amino acids. The A/E ratio (where A = individual essential amino acids and E= total essential amino acids) was calculated using the equation (Wilson and Poe, 1985):

[each essential amino acid ÷ (total essential amino acids + cystine + tyrosine)]x 1000.

The A/E ratio provides an indication of the proportion of individual EAA requirements of the animal. The similarity of the A/E ratios of the whole body of a species to that of an ingredient is thought to provide a reliable indication whether the EAA composition of the latter has the potential to meet the requirements of the species.

The EAA Index is a method of comparing the EAA profiles of the waste sample and the target fish species. EAAI is also based on A/E ratios, and is determined by the following formula (Castell and Tiews, 1980; Hayashi et al., 1986; Penaflorida, 1989);

$$\text{EAAI} = \sqrt[n]{\frac{aa_1 \times aa_2 \times \ldots\ldots \times aa_n}{AA_1 \times AA_2 \times \ldots\ldots \times AA_n}}$$

Where aa = the A/E ratio in the ingredient for a given amino acid and so on; AA_1 = A/E ratio in the fish carcass for a given amino acid. *n* the number of essential amino acids. The numerical values of aa_1/AA_1 , aa_2/AA_2 … are set to 0.01 minimally and 1 maximally. An EAAI closer to 1 is indicative of the degree of conformity of the EAA profiles of the ingredient and the fish species and therefore, the potential of the ingredient to meet the EAA requirements of the species.

6 Results

6.1 Industry Audit

The main sources of seafood processing and other aquatic wastes in Victoria with potential for use in aquafeeds were identified in this study as:

- Commercial fisheries (including aquaculture) processors.
- Pet food manufacture.
- Other food processing wastes - *e.g.* dairy industry.
- Plankton from waste treatment ponds.

6.1.1 Commercial Fisheries (Including Aquaculture) Processors

Fishing and aquaculture is the fifth most valuable Australian rural industry after wool, wheat, beef and dairy. In1998/99, the seafood industry was worth $2,039 million to the Australian economy (ABARE, 1999, www.abareconomics.com) and provided around 22,000 jobs in the catching and harvesting sector, with around 4,000 in seafood processing. Compared with other Australian states, fisheries production in Victoria is low (4% of national output) due primarily to its relatively limited coastline and associated aquatic resources. The three main sources of seafood landed in Victoria are the bay and inlet fishery (State Government controlled), the south-east trawl fishery (Commonwealth Government controlled) and the aquaculture industry (Table 6.1). In 1998/99, Victorian wild fisheries and aquaculture landed 8,569 tonnes of product with a value of approximately $90 million (Fisheries Victoria, 2000). In addition, approximately 14,500 tonnes valued at $30 million were landed in Victoria from the Commonwealth fishery.

The combined fishing industry landed an estimated 26,000 tonnes of product in Victoria in 1998/99 at a value of $130 million. In Victoria, around 2,250 jobs are directly related to the seafood processing industry, with 750 in the harvesting sector and 580 in the processing industry. Many more jobs are indirectly related to the industry through service and support industries. Victoria exports over 4,000 tonnes of processed seafood valued at $122 million in 1996/97 (MAFRI, pers. comm.). These exports are dominated by rock lobster and abalone which make up 80% of the total.

When returns for 1998/99 (Table 6.1) are compared with returns for 1993/94 (Victorian Fisheries, 1995), it is clear that significant changes have occurred in the species composition of the landed catches in recent years. Overall, total catches have fallen from 34,314 tonnes in 1993/94 (value $150 million) to 26,000 tonnes in 1998/99.

Table 6.1 Summary of value, quantity and source of fish and seafood commonly sold in Victoria .

	Tonnes	Value ($'000)	
FISH – Victorian Inshore Bays and Inlets 1998/1999 (Fisheries Victoria, 2000)			
Anchovy	141	249	Mainly petfood/ bait
Australian Salmon	690	805	
Black Bream	198	1,524	
Carp European	984	729	Fillets for Asian markets Small fish petfood/ cray bait
Flathead Sand	13	20	
Flathead Rock	54	176	
Garfish	14	43	
Luderick	48	59	
Mullet Sea	17	19	
Mullet Yellow Eye	144	149	
Pilchards	277	679	Mainly petfood/ bait
Snapper	91	620	
Whiting (King George)	223	1,671	
TOTAL (inc other species)	**3,775**	**10,113**	
FISH – South East Trawl Fishery (Caton and McLoughlin, 2000)			
Blue Eye	476	3,600	
Flathead Tiger	2,664	5,100	
Grenadier Blue	5,734	8,800	
Ling	1,894	5,600	
Morwong	883	1,400	
Orange Roughy	4,174	12,70 0	
Redfish	1,770		
Trevally Silver	233		
Warehou Blue	1,012	1,800	
Whiting School	638	1,100	
TOTAL (inc other species)	28,964	59,200	
VICTORIAN SHARE	**14,482**	**29,600**	
SOUTHERN SHARK FISHERY (Caton and McLoughlin, 2000 + Fisheries Victoria, 2000)			
Shark Gummy	1,523+60		
Shark Saw	240+3		
Shark School	579+5		
TOTAL (inc other species)	**2,753**	**11,360**	
ROCK LOBSTER / GIANT CRAB (Fisheries Victoria, 2000)			
Crab Giant	50	1,548	High value exports
Lobster Rock	572	16,706	High value exports
TOTAL	**622**	**18,254**	
CEPHALOPOD (Caton and McLoughlin, 2000 + Fisheries Victoria, 2000)			
Calamari	53	272	
Squid Arrow	439+ 3	700+ 4	
TOTAL	**495**	**976**	
ABALONE (Fisheries Victoria, 2000)	**1,439**	**43,385**	
SCALLOPS (Fisheries Victoria, 2000)	**19**	**37**	
AQUACULTURE (O'Sullivan and Dobson, 2000)			
Rainbow trout	1,425	7,195	
Mussels	535	1,520	
Eels	225	2,700	

TOTAL (inc other species)	**2,334**	**17,736**
VICTORIAN TOTAL	**25,919**	**131,461**

The main cause of this fall in production was the dramatic decline in the scallop fishery (8,800 tonnes in 1993/94 to 19 tonnes in 1998/99) and the reduced landings of high volume-low value fish such as anchovies and pilchards (3,367 tonnes in 1993/94 to 418 in 1998/99). In the Commonwealth fishery, declines in the catch of orange roughy and school whiting have been offset by increases in the other catches (Table 6.1).

For the purposes of this audit it has been assumed that the volume of waste produced annually by the seafood industry in Victoria is directly proportional to the volume of each species handled by the fishers/producers, processing industry and wholesalers/retailers. In addition, some processors and wholesalers, particularly at the Melbourne Wholesale Fish Market, import fisheries products from inter-state. A recent study (Read Sturgess, 1995) estimated that in 1994/95, 35.7% of all fish supplied to agents in the MWFM came from interstate (NSW 24%, SA 4.9%, Tas 6.7%). The turnover of the MWFM is approximately 12-13,000 tonnes annually.

The route of fish landed in Victoria from harvest to consumer is shown in Figure 6.1, together with stages where waste can be generated. Although by-catch is a major waste loading associated with the fishing industry, it has not been specifically considered in this study as it is not returned to port. Other wastes which are not returned to port include offal from fish cleaned and gutted off-shore. Based on the fisheries landings in Victoria, an overall picture of the potential waste resources which could be available for the production of aquafeeds may be assessed (Table 6.2) using assumptions of the waste:total biomass relationship. In addition to these loadings there are additional wastes generated by the secondary processing of fish into value-added products some of which utilises fish bought interstate or overseas.

Although this simplistic assessment indicates that there is potentially a large quantity of waste available for use in aquafeed production, the suitability of that waste is largely dependent on the reliability of the waste supply and the geographic spread of the waste producers producing useable quantities of waste. Table 6.2 also shows that the wastes generated by the aquaculture industry (represented by Inland Fish) is relatively small compared with the wastes derived from the marine capture fishing industry.

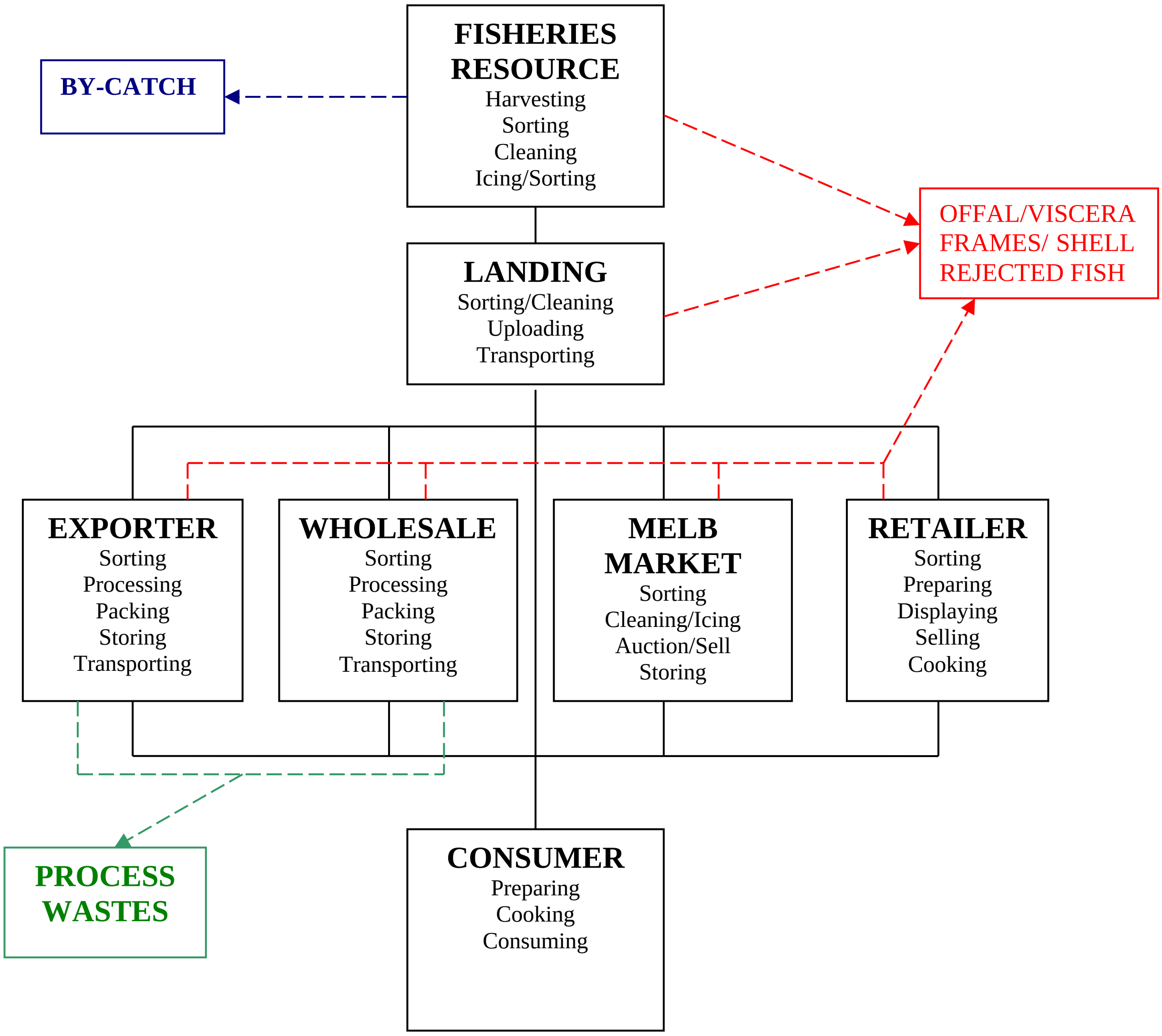

Figure 6.1 Potential waste sources from the seafood industry in Victoria.

Table 6.2: Potential waste resources from Victorian fish landings.

	Total Catch (tonnes)	Potential Waste (tonnes/annum)	
Inland Fish (T&S)	1,425	Frames & Offal (17%)	240
Marine Fish			
B& I *	3,375	Frames & Offal	
SETF	14,482		
Total	17,857	20-50%	3,500-8,900
Shark	2,753	50%	1,376
Squid	495	25%	120
Scallop	19	Shell (60%)	12
		Guts (20%)	4
Abalone	1,450	Shell (33%)	483
		Guts (33%)	483
TOTAL			**6,218-11,618**

* Excludes pilchards and anchovies which usually go directly for petfood.

6.1.1.1 Reliability of Waste Supply.

- Inland Finfish. Inland finfish production is dominated by the aquaculture production of salmonids in Victoria. The industry is well established and has a stable production of around 1,400–2,000 tonnes per annum. Most farms produce pan sized (200-300g) fish for the domestic and export market and the fish are gutted on-site after harvest. Around 15-17% of the harvest is waste offal. The industry is concentrated in the Goulburn-Broken catchment area of Victoria although there are some small farms outside this area.
- Marine Finfish. Although the total volume of scale fish landed from the Bay and Inlets Fisheries to Victorian ports has decreased in recent years, within that decline there are distinct trends at species group level. In 1998/99 the most important species by volume were carp, Australian salmon, anchovy, pilchards and King George whiting (Table 6.1). The catches of anchovy and pilchard have declined dramatically in recent years. These two species are generally used directly for petfood and do not enter the marketing or processing chain. Carp have been used for low-value petfood and fertiliser as well, but in recent years one company has opened up additional higher-value markets in Europe and Israel for carp fillets for human consumption. The increasing fishing effort in this sector has resulted in steadily increasing production over recent years from 497 tonnes in 1995/96 to 984 tonnes in 1998/99. It is likely that this sector will continue to expand in the future subject to availability of wild carp stocks.

Most of the marine finfish in Victoria is landed east of Port Phillip Bay, particularly around the Paynesville/Lake Tyers area. Although a proportion of the catch is processed at the port of landing, some is immediately loaded onto trucks and transported to the MWFM. The south-east trawl fishery supplies most of the fresh fish to NSW, Victoria and Tasmanian markets. Although more than 100 species are taken by the fishery, a select group of 17 species provide the bulk (>80%) of the catch and are subject to total allowable catch (TAC) limits (Caton and McLoughlin, 2000). Approximately 50% of the total south-east trawl fishery catch is sold in Victoria (Table 6.1). Of the 17 species with TAC quotas only one is thought to be overfished (eastern gemfish), while five (blue warehou, flathead, jackass morwong, ocean perch and redfish) are fully fished, and orange roughy is fully fished with declining catches. The remainder are under-fished or of uncertain status.

- Shark. Quotas have recently been imposed on the school and gummy sharks. School sharks are currently overfished and the quota will reduce catches significantly to enable the re-building of the adult population (Caton and McLoughlin, 2000). Current gummy shark catches are likely to be sustainable (Terry Walker, MAFRI pers. comm.).
- Scallop. The scallop fishery has declined from 2,657 tonnes in 1995/96 to just 19 tonnes in 1998/99 due mainly to the buy-back of licences in Port Phillip bay. The scallop fishery recovered slightly in 1999/2000 (346 tonnes) predominantly from Bass Strait, but was still low compared with former years. The developing scallop aquaculture industry in Port Phillip Bay is a significant future source of scallop product, particularly if a shellfish hatchery is established in Victoria.
- Squid. Squid are caught in targeted squid jigging operations in the Southern Squid Jig Fishery and as a by-catch of other fishing. The Southern Squid Jig Fishery is not currently subject to a formal management plan and squid catches can be highly variable from season to season.
- Abalone. Abalone are fished under a quota system and so the volume of processed product is relatively stable on an annual basis.

6.1.1.2 Location of Seafood Processors and Major Waste Producers

The geographic spread of waste producers was assessed as part of the industry audit, the results of which are shown in Tables 6.3-6.5.

The Yellow Pages listed 48 companies as registered seafood processors (Table 6.3) and 185 companies as wholesale fish processors. However, it was apparent that many of the companies listed as wholesalers also processed large quantities of fish. The distinction between seafood processors and wholesalers is blurred as many processors also wholesale fish and wholesalers undertake some processing or cleaning to make their product ready for market. The situation was clarified by contacting all seafood processors and wholesale fish suppliers listed in the yellow pages and re-classifying them. In total, 213 companies were contacted and 100 were confirmed as carrying out some form of processing (this figure includes the Agents and Provedores at the MWFM). A total of 99 companies were identified as wholesalers only, and a further 12 (6%) could not be contacted by telephone.

Table 6.3: Seafood processors and wholesalers in Victoria, January 2001

	No Companies listed in Yellow Pages	Actual Number (this survey)
Seafood Processors	48	100
Wholesale fish suppliers	185	99
Fish and seafood retail	330	

Of the 100 companies identified as fish processors (Table 6.4), 74 were producing wastes as a result of their processing activities, 22 were producing no waste and four (4%) did not reply. The main reasons given for fish processors producing no waste were:

- Fish purchased already filleted and clean (32%)
- Head office for interstate processing company (4%)
- No longer processing/closed (27%)
- Mussel or calamari producer- no wastes (23%).

As shown in Table 6.4, the companies producing processing waste are dominated by the MWFM (19%) and finfish processors (39% marine finfish, shark and inland fish). These two sectors are also responsible for the majority of seafood processing waste in Victoria (73%).

Table 6.4: Response to questionnaire survey of fish processors.

	Number	%	Recorded Waste Output (t/yr)
Total number of companies	100		
Survey replies	96	96	
Producing no waste	22	23	
Producing waste	75	77	
Of the companies producing waste:			
Abalone	9	12%	195
Mixed seafood	18	24%	365
Inland fish	6	8%	177
Finfish	20	27%	1,160
MWFM	14	19%	2,500
Shark	4	5%	600
Other	4	5%	50
TOTAL			**5,047**

Only three of the nine abalone processors contacted could give an accurate estimate of the volume of waste they produced as most had established markets for both the shell and gut wastes they produced. The shells were sold and exported overseas and the viscera were sold or given away for bait or fertiliser. One company manufactured abalone sauce from the gut waste. Two companies, both located in the Melbourne/Geelong area had the waste picked up by a disposal company, with one of the companies paying $30,000 per annum for waste disposal.

Mixed seafood includes those companies which process more than one seafood type, and therefore this category was difficult to classify (18 companies). Generally, these companies were fairly small waste producers (12 companies < 120 tonnes per annum total waste) although one recorded an annual output of 150 tonnes which was disposed of by a waste company. Most of the small companies disposed of their waste through disposal companies, but did not record how much it cost on annual basis. Of the companies that did know, costs ranged from $2,000 to $30,000 per year. Five companies had alternative uses for their wastes such as petfood, or disposal to farmers or fishermen for fertiliser and bait.

The largest producers of waste from inland fish processors came from two large salmonid farms in the Goulburn Valley. Both of these farms currently bury their waste at a combined cost of $10,000 per annum.

Finfish processors were the second largest producer of seafood processing waste after the MWFM. Of the 20 companies contacted, 7 were producing significant quantities (> 50 t per year) of processing waste which was disposed of to landfill *via* disposal companies (four companies). The cost of disposal to landfill varied widely depending on the location of the company with one reporting costs of $30,000/yr and others reporting $17,500/yr in Geelong and $8,000/yr per year in Lakes Entrance. One of the companies had a local farmer pick up the waste for fertiliser, and another gave their waste away for cray bait. The smaller waste-producing companies gave their "head and tail" waste away for craybait (three companies), used the offal and frames for fish stock (one company), and the remainder were charged by disposal companies to remove the waste.

Four companies were identified as only processing shark, and one company recorded a waste production of 500-600 tonnes per annum. This company disposed of the waste through a disposal company which subsequently uses it for petfood. The other shark processors produce small amounts of waste by comparison.

When the processors producing waste are sorted by geographic area (Table 6.5) it is clear that there is a significant volume of waste produced in the Melbourne and Geelong area. In addition, discussions with fish processors at the MWFM have indicated that if a processing plant was set up near there, the quantity of waste collected could be doubled by encouraging small operators who buy fish from the market every day to return wastes the next day.

An estimated total of 4,100 tonnes of processing waste is currently available in the Melbourne-Geelong area.

The quantities of waste available in the other key areas of Lakes Entrance, Portland and inland are considerably smaller, but still significant. The proximity of the major fishing ports specifically to Lakes Entrance and Portland offer some scope for the additional utilisation of by-catch (6.1.5) in any processing plant which was set up.

Table 6.5: Geographic location of fish processors.

	No processors	Waste Type	Current Disopsal	Quantity (tonnes)	Estimated Cost
MWFM	15 3 Agents 12 Provedores	Finfish, shark and shell fish	Collected in central disposal area and picked up by disposal company (DC).	2,500	Nil
Melbourne	25	• 9 fin fish • 3 abalone • 4 shark • 8 mixed	• 8 DC., 1 fertiliser • 1 landfill • 1 DC • 7 DC, 1 fertiliser	• 770 • n/a • 620 • 210	• $45,000 • $30,000 • n/a • n/a
Geelong	10	• 4 finfish • 2 abalone • 4 mixed	• 3 DC, 1 bait • 1 DC, 1 bait • 3 DC, 1 bait	• 160 • 80 • 90	• $25,000 • $2,000 • $35,000
Portland	9	• 3 fin fish • 2 abalone • 4 mixed	• Bait • Sold • Petfood/ landfill	• 20 • 120 • 20	• n/a • n/a • $2,000
Lakes Entrance	10	• 5 finfish • 2 abalone • 3 mixed	• 3 DC • To farmers • 1 fertiliser	• 710 • n/a • 60	• $10,000 • n/a • n/a
Inland	6	• fin fish	Burial/ fertiliser	• 175	• $15,000
		TOTAL		5,535	$164,000

6.1.2 Petfood Manufacturers

Petfood manufacturers currently utilise a large proportion of processing waste from the seafood industry. However, in the processing from fish waste to catfood, significant quantities of waste are generated through plant cleaning and process line wastage. A large petfood manufacturing plant in Wodonga, Victoria produces 3,250 tonnes of process waste and an additional 11,000 tonnes of activated sludge on an annual basis. The process wastes are currently given to a renderer free of charge, for conversion to fertiliser, whilst the activated sludge is disposed of to landfill at a cost of $27,500/yr.

6.1.3 Dairy Processing Industry

Dairy processing factories produce large volumes of wastewater which contains milk solids and fats. These are removed during the filtration process and disposed of to landfill. One milk processing plant alone at Cobden produces 60 tonnes per annum of filter waste.

In addition to standard milk processing wastes, a specialised plant produces a filter cake of pure casein. This plant produces 141 tonnes of filter cake per year and disposes of it to landfill at a cost of $56,400.

6.1.4 Plankton from Waste Treatment Ponds

Plankton occurs naturally in all waters and is particularly prolific in nutrient-rich wastewaters. Technology has been developed to harvest the plankton from these ponds and a company has been granted a licence to harvest the plankton from the Werribee Sewage Treatment Plant. The company has harvested around 1,000 tonnes from the ponds per annum, but estimates that production can be much higher.

6.1.5 Bycatch

By-catch was not specified in the terms of reference for this project, but has since been recognised as a major source of waste which could complement the processing resources identified in this study and potentially make the venture economically viable through economies of scale.

A recent study of the South East Trawl Fishery has estimated that up to 50% (by weight) of the catch may be discarded in certain fisheries (Knuckey and Liggins, 1999). Even in fisheries with low discard rates, by-catch still makes up 10-30% of the total catch. Given that the recorded catch of the SE Trawl Fishery was 29,000 tonnes in 1998/99, the associated by-catch may be estimated at between 2,900 and 14,500 tonnes.

6.2 Chemical Analysis

The identification codes for the waste samples analysed are shown in Table 6.6.

Table 6.6 Identification codes for waste samples submitted.

Sample	ID Code	Group code
Trout offal	TO	
Marine fish secondary processing wastes	SFW	FISH
Carp roe	CR	WASTES
Carp frames and viscera	CO	
Marine fish frames	FF2	
Scallop waste	SG	
Marine fish frames	FF1	
Marine fish viscera	FV	
UBA catfood waste	CFW	
UBA bone meal waste	BMW	PETFOOD
UBA dog food waste	DFW	WASTES
UBA general waste	GW	
Plankton	ZP	PLANKTON
Dairy wastes (Casein)	DW1	DAIRY
Dairy waste (Filter waste)	DW2	
Chilean fishmeal	FM	FISHMEAL

6.2.1 Proximate composition

The proximate composition, on a dry matter basis, of the different types of waste products and that of fishmeal is given in Table 6.7 and it is evident there were major differences in the protein, lipid and ash content of the various waste products.

Protein content ranged from 31.9% (TO) to 82.9% (DW1) and in some of the waste products, (*e.g.* CR, CO, CFW and DW1) the protein content was higher than fishmeal.

Lipid content ranged from 2.1% (DW1) to 56.8% (TO). Trout offal had far higher lipid content than the other fish waste samples. GW and DW2 were also high.

Ash content ranged from 0.9% (DW1) to 50.8% (SG). The ash content of the fish waste samples was primarily dictated by the quantity of bone in the waste.

Moisture content of fish waste samples varied between 55.3% (TO) and 77.6% (SFW). Petfood and dairy waste samples showed similar moisture contents (51.7%-75.9%) but plankton (ZP) was far higher at 93.2%.

6.2.2 Amino acid composition, A/E ratio and EAAI.

The amino acid composition and A/E ratio of the waste products and fishmeal is given in Tables 6.8 and 6.9, respectively.

The total EAA content ranged from 529 to 4203 µ moles g^{-1} dry matter in SG and DW1, respectively, but only CR (1680µ moles g^{-1}) and DW1 (4,203 µ moles g^{-1}) had a higher total EAA content than that of fishmeal (1628 μ moles g^{-1}). The EAA found in highest quantity was leucine in the case of TO, CO, CR, CFW, ZP, and DW1, and lysine in the case of FV, FF1, FF2, SFW, BMW, DFW, GW, DW2 and fishmeal. In all the waste products, except in FV, SFW, DW1 and DW2, the most dominant NEAA was glycine. The total amino acid (TAA) content was higher than fishmeal (3208 μ moles g^{-1}) only in CR (3467 μ moles g^{-1}) and DW1 (9076 μ moles g^{-1}).

The results of the EAAI, calculated using A/E ratios in the different waste products to that of A/E ratio in fish carcass of the three fish species (Murray cod, rainbow trout, shortfin eel) under consideration, are given in Tables 6.10, 6.11, 6.12, respectively. An EAAI closer to 1.0 is indicative of the degree of similarity of the EAA profile of the waste product to that of the fish species.

In the case of Murray cod (Table 6.10) the best EAAI was in respect of fishmeal followed by FV, FF1, FF2 and SFW, where all these waste products had a similar EAAI value. The EAAI of BMW and DFW had the lowest value with regard to Murray cod. The best EAAI of rainbow trout was also fishmeal (Table 6.11), followed by FV ≥ FF2 > FF1 > SFW. In the case of rainbow trout, the lowest EAAI value was found in BMW and DFW waste products. The fishmeal gave the best EAAI value for shortfin eel (Table 6.12) followed by FF2, which gave a slightly higher value than FV, FF1 and SFW. Here again BMW and DFW gave the lowest EAAI values.

6.2.3 Fatty acid composition

The fatty acid composition of the different waste products and that of fishmeal is given in Table 6.13. There were major differences in the amount of individual fatty acids as well as in the major groups of fatty acids present in each of the ingredients. The highest amount of linoleic (18:2n-6) and linolenic (18:3n-3), biologically active base fatty acids, in μg mg^{-1} of sample were found in TO (39.91±1.9) and ZP (19.9±0.3), respectively. The amount of total n-3 in FF1(43.0±0.8), FV(36.96±0.4) and TO (36.46±0.3) was higher than in fishmeal (31.96±0.4). Trout offal had the highest amount of total n-6 (47.9±2.2). The highest PUFA amount was found in TO (84.36±2.6) followed by FF1, FV, CR and ZP.

6.2.4 Estimates of selected mineral elements.

The amount of six selected mineral elements in the waste products and in fishmeal is given in Table 6.14. Major differences in the concentrations of the different minerals in the waste products were evident, such as for example all minerals were found in lower concentration in DW1 when compared to the others.

6.3 Results of Digestibility Trials

Due to technical difficulties, the results of the digestibility studies conducted on five of the waste products in Murray cod and shortfin eel were not satisfactory and are not reported here. In these experiments the variability in the digestibility estimates obtained (apparent dry matter and protein digestibility) were extremely high, and did not appear to be realistic estimates.

Chemical analysis of faecal samples will be repeated in due course and the ensuing results will be provided later on as an addendum to this report.

Table 6.7: The mean (±se) percent moisture, protein, lipid and ash content in waste products and fish meal. Protein, lipid and ash are given on a dry matter basis based on three sub-samples. Values with the same superscript in each row are not significantly different (p> 0.05).

Proximate Composition	TO	CO	CR	SG	FV	FF1	FF2	SFW	CFW	BMW	DFW	GW	ZP	DW1	DW2	FM
Moisure	55.3^{b} ±3.0	72.9^{efg} ±0.3	68.8^{def} ±0.08	75.7^{fg} ±0.6	---	61.5^{c} ±0.8	74.8^{efg} ±0.6	77.6^{g} ±1.0	73.6^{efg} ±0.06	56.4^{b} ±0.2	75.9^{fg} ±0.1	67.7^{de} ±0.9	93.2^{h} ±0.04	51.7^{b} ±0.01	65.6^{cd} ±0.1	7.7^{a} ±0.05
Protein	31.9^{a} ±0.8	67.3^{hi} ±0.3	69.7^{ij} ±0.2	37.5^{cd} ±0.5	42.9^{e} ±0.02	53.1^{f} ±1.5	62.9^{g} ±0.2	35.6^{bc} ±0.9	70.5^{j} ±1.8	32.7^{ab} ±0.2	34.9^{abc} ±0.1	40.0^{d} ±1.0	62.5^{g} ±0.02	82.9^{k} ±0.5	43.8^{e} ±0.1	66.5^{h} ±0.2
Lipid	56.8^{l} ±0.2	17.1^{e} ±0.1	13.2^{c} ±0.1	6.6^{b} ±0.1	28.7^{i} ±0.3	31.2^{j} ±0.6	14.9^{d} ±0.5	12.6^{c} ±0.2	18.4^{f} ±0.1	25.4^{h} ±0.0	19.3^{g} ±0.06	35.4^{k} ±0.08	12.7^{c} ±0.09	2.1^{a} ±0.06	34.9^{k} ±0.2	12.6^{c} ±0.3
Ash	3.1^{b} ±0.1	6.6^{cd} ±0.03	5.4^{c} ±0.2	50.8^{i} ±0.2	8.8^{e} ±0.4	16.1^{g} ±0.7	16.8^{g} ±0.3	1.3^{a} ±0.03	6.6^{cd} ±0.1	38.2^{h} ±0.2	16.5^{g} ±0.02	7.3^{d} ±0.7	6.1^{c} ±0.01	0.9^{a} ±0.0	8.4^{e} ±0.0	11.8^{f} ±0.02

Table 6.8: Mean amino acids (±se) in µ moles g^{-1} dry matter of waste products and fish meal.

Amino acid	**TO**	**CO**	**CR**	**SG**	**FV**	**FF1**	**FF2**	**SFW**	**CFW**	**BMW**	**DFW**	**GW**	**ZP**	**DW1**	**DW2**	**FM**
Arginine	77.3 ±3.5	145.6 ±3.1	168.0 ±1.1	87.5 ±3.0	81.1 ±3.2	109.7 ±3.8	104.2 ±2.9	103.1 ±1.4	178.5 ±8.0	54.5 ±6.1	71.5 ±1.5	67.3 ±0.6	120.8 ±5.2	246.9 ±6.6	73.7 ±1.5	169.0 ±5.7
Histidine	25.8 ±3.6	58.4 ±3.1	86.8 ±2.9	26.1 ±3.0	37.8 ±4.0	43.9 ±0.8	49.4 ±2.2	39.7 ±2.4	69.8 ±4.0	8.7 ±1.1	27.7 ±1.5	22.1 ±0.7	39.6 ±4.7	263.4 ±6.8	60.7 ±2.3	95.6 ±3.7
Isoleucine	61.9 ±3.1	133.8 ±2.3	185.5 ±3.1	50.0 ±2.6	76.9 ±3.9	60.1 ±2.5	64.6 ±2.4	93.1 ±3.3	106.6 ±4.9	14.7 ±1.8	34.2 ±1.1	40.7 ±0.5	85.9 ±7.5	277.1 ±8.5	120.9 ±3.2	128.2 ±5.6
Leucine	115.7 ±11.6	234.0 ±6.7	309.5 ±2.1	78.4 ±6.7	132.5 ±9.6	84.4 ±2.8	92.5 ±2.9	183.6 ±5.2	245.2 ±12.5	39.9 ±5.0	98.7 ±4.0	98.3 ±4.3	146.8 ±12.8	1036.2 ±54.3	294.6 ±8.0	261.4 ±14.2
Lysine	109.1 ±12.9	194.8 ±22.7	194.5 ±14.8	66.8 ±2.5	144.2 ±18.1	130.8 ±9.5	140.4 ±13.9	198.6 ±14.6	187.1 ±30.9	399.8 ±19.2	835.6 ±44.0	254.3 ±14.4	115.2 ±7.2	601.9 ±79.8	297.4 ±27.6	386.4 ±18.6
Methionine	40.9 ±4.8	100.7 ±5.2	134.5 ±5.5	35.0 ±3.1	53.8 ±2.9	59.7 ±9.2	53.3 ±2.2	64.0 ±0.5	63.5 ±4.4	nd	19.6 ±0.2	23.4 ±0.5	55.0 ±5.7	299.3 ±6.8	74.3 ±1.7	96.2 ±2.8
Phenylalanine	53.9 ±6.6	103.0 ±0.5	135.8 ±3.7	46.5 ±7.7	71.6 ±6.6	57.4 ±1.4	61.1 ±1.8	81.6 ±2.3	139.8 ±2.0	20.4 ±2.1	48.2 ±1.2	52.4 ±3.1	84.8 ±8.4	580.4 ±7.4	137.7 ±15.5	125.1 ±3.7
Threonine	85.4 ±6.0	167.8 ±4.2	210.9 ±1.1	80.2 ±3.1	109.1 ±6.0	93.3 ±1.3	109.4 ±3.9	122.9 ±2.1	154.5 ±7.8	27.4 ±3.4	65.2 ±1.6	61.1 ±0.5	120.0 ±6.2	413.2 ±16.4	129.1 ±2.9	186.8 ±7.5
Valine	88.7 ±5.4	189.6 ±4.0	254.2 ±2.7	58.8 ±3.8	101.7 ±6.1	72.3 ±4.7	76.3 ±2.3	116.9 ±4.0	176.6 ±9.3	29.8 ±3.9	65.4 ±2.1	65.9 ±1.7	128.1 ±10.3	485.1 ±17.5	170.4 ±4.5	178.7 ±7.9
å **EAA**	**659 ±48**	**1328 ±49**	**1680 ±29**	**529 ±30**	**809 ±51**	**712 ±20**	**751 ±25**	**1003 ±21**	**1322 ±78**	**595 ±38**	**1266 ±37**	**685 ±19**	**896 ±62**	**4203 ±193**	**1359 ±41**	**1628 ±59.4**
Alanine	111.2 ±8.1	215.0 ±8.1	266.3 ±2.6	81.9 ±5.1	126.4 ±10.3	108.8 ±3.5	106.5 ±4.4	136.5 ±6.4	231.6 ±14.2	101.0 ±13.0	130.5 ±7.9	122.4 ±0.9	144.2 ±8.7	327.4 ±20.2	147.2 ±8.8	257.7 ±17.0
Aspartic	66.1 ±5.6	82.7 ±3.7	91.7 ±4.4	68.1 ±4.4	72.4 ±7.3	86.3 ±2.9	100.9 ±3.5	90.2 ±5.0	100.1 ±5.3	35.0 ±4.7	67.1 ±2.6	57.3 ±1.7	66.3 ±3.1	209.3 ±16.2	149.5 ±12.7	155.8 ±9.2
Cystine	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	181.2±4.6	nd	15.0±1.1
Glutamic	102.9 ±7.3	175.7 ±7.0	214.1 ±7.6	87.9 ±5.0	113.4 ±8.9	75.0 ±2.7	90.4 ±2.8	174.1 ±8.6	202.7 ±10.5	62.0 ±8.1	110.1 ±5.7	146.9 ±2.7	99.2 ±5.1	685.1 ±51.0	384.6 ±30.8	229.6 ±13.4
Glycine	185.6 ±6.9	397.1 ±4.3	462.1 ±2.0	343.2 ±6.4	204.5 ±6.4	330.0 ±23.0	276.6 ±3.9	157.6 ±1.2	509.8 ±14.8	321.0 ±34.4	304.8 ±6.1	302.4 ±2.9	184.3 ±9.3	436.1 ±9.1	138.1 ±0.8	379.4 ±10.3
Proline	118.3 ±6.3	245.1 ±1.3	299.6 ±1.3	143.8 ±1.2	208.8 ±1.5	206.7 ±7.9	162.1 ±1.3	111.6 ±0.4	344.1 ±3.2	122.8 ±11.2	140.5 ±1.5	157.6 ±0.8	146.0 ±4.1	1462.6 ±13.4	305.5 ±3.3	212.1 ±4.5
Serine	83.0 ±7.4	234.5 ±5.6	304.8 ±1.7	95.8 ±3.8	127.8 ±6.7	115.6 ±3.3	121.2 ±4.6	126.0 ±2.3	194.6 ±9.6	45.6 ±5.7	83.2 ±2.2	92.0 ±0.9	118.4 ±6.2	573.6 ±26.0	192.1 ±4.9	194.2 ±8.5

Tyrosine	50.6 ±5.6	113.5 ±11.0	148.8 ±14.7	32.6 ±6.4	66.4 ±6.4	62.2 ±10.6	68.1 ±8.1	76.1 ±9.0	119.0 ±17.0	15.5 ±1.5	39.9 ±0.6	40.4 ±0.6	95.9 ±10.8	996.9 ±4.7	144.4 ±1.4	137.0 ±3.8
å **NEAA**	**717** **±42**	**1463** **±37**	**1787** **±25**	**853** **±29**	**920** **±36**	**984** **±33**	**925** **±24**	**872** **±27**	**1702** **±71**	**703** **±76**	**876** **±23**	**919** **±4**	**854** **±39**	**4872** **±141**	**1461** **±61**	**1580** **±56.6**
å **TAA**	**1377** **±89**	**2791** **±85**	**3467** **±35**	**1383** **±58**	**1729** **±88**	**1697** **±33**	**1677** **±48**	**1876** **±42**	**3024** **±149**	**1298** **±112**	**2142** **±25**	**1605** **±21**	**1751** **±101**	**9076** **±334**	**2820** **±98**	**3208** **±115**

Table 6.9: A/E ratios of the essential amino acids of the waste products and fish meal.

Amino acid	TO	CO	CR	SG	FV	FF1	FF2	SFW	CFW	BMW	DFW	GW	ZP	DW1	DW2	FM
Arginine	110	101	92	156	93	142	127	95	124	88	55	93	122	46	49	95
Histidine	35	40	47	46	43	57	60	36	48	14	21	30	39	49	40	54
Isoleucine	88	93	101	89	88	77	79	86	74	24	26	56	86	51	80	72
Leucine	162	162	169	134	151	109	113	170	170	64	76	135	147	192	196	146
Lysine	155	134	106	120	163	168	170	183	127	657	638	349	116	110	196	217
Methionine	57	70	73	62	61	76	65	59	44	0	15	32	55	55	49	54
Phenylalanine	75	72	74	81	82	74	74	75	98	33	37	72	85	108	91	70
Threonine	120	116	115	143	124	121	133	114	107	44	50	84	121	76	86	104
Valine	125	132	139	104	116	93	93	108	123	48	50	90	129	90	113	100

Table 6.10: A/E ratio of essential amino acids in waste products to that of Murray cod (Aa/AA) and Essential Amino Acid Index (EAAI) Aa= A/E ratio of the waste product; AA = A/E ratio of the fish carcass.

Waste Product Murray cod	Arginine	Histi.	Isoleucin e	Leucine	Lysine	Methion.	Phenylal.	Threon.	Valine	EAAI
TO	1.0	0.71	1.0	1.0	0.80	0.80	1.0	1.0	1.0	0.91
CO	1.0	0.81	1.0	1.0	0.69	1.0	1.0	1.0	1.0	0.93
CR	0.94	0.95	1.0	1.0	0.55	1.0	1.0	1.0	1.0	0.92
SG	1.0	0.92	1.0	0.86	0.62	0.93	1.0	1.0	1.0	0.91
FV	0.96	0.86	1.0	0.94	0.85	0.92	1.0	1.0	1.0	0.94
FF1	1.0	1.0	1.0	0.68	0.88	1.0	1.0	1.0	1.0	0.94
FF2	1.0	1.0	1.0	0.7	0.89	0.98	1.0	1.0	1.0	0.94
SFW	0.98	0.74	1.0	1.0	0.95	0.89	1.0	1.0	1.0	0.94
CFW	1.0	0.97	1.0	1.0	0.66	0.66	1.0	0.96	1.0	0.90
BMW	0.91	0.28	0.39	0.4	1.0	0.01	0.48	0.4	0.61	0.33
DFW	0.56	0.42	0.43	0.47	1.0	0.23	0.53	0.45	0.64	0.49
GW	0.96	0.61	0.92	0.84	1.0	0.49	1.0	0.75	1.0	0.82
ZP	1.0	0.79	1.0	0.92	0.60	0.83	1.0	1.0	1.0	0.89
DW1	0.47	0.98	0.85	1.0	0.57	0.84	1.0	0.68	1.0	0.79
DW2	0.5	0.81	1.0	1.0	1.0	0.74	1.0	0.77	1.0	0.85
Fish meal	0.98	1.0	1.0	0.91	1.0	0.81	1.0	0.94	1.0	0.95

Table 6.11: A/E ratio of essential amino acids in waste products to that of rainbow trout (Aa/AA) and Essential Amino Acid Index (EAAI)
Aa= A/E ratio of the waste product ; AA = A/E ratio of the fish carcass.

Waste Product **<u>Rainbow trout</u>**	**Arginine**	**Histid.**	**Isoleu.**	**Leucine**	**Lysine**	**Methio.**	**Phenylal.**	**Threon.**	**Val.**	**EAAI**
TO	1.0	0.65	1.0	1.0	0.70	0.92	1.0	1.0	1.0	0.91
CO	1.0	0.74	1.0	1.0	0.60	1.0	1.0	0.97	1.0	0.91
CR	1.0	0.87	1.0	1.0	0.48	1.0	1.0	0.96	1.0	0.90
S G	1.0	0.85	1.0	0.93	0.54	1.0	1.0	1.0	1.0	0.91
FV	1.0	0.79	1.0	1.0	0.74	1.0	1.0	1.0	1.0	0.94
FF1	1.0	1.0	1.0	0.73	0.76	1.0	1.0	1.0	1.0	0.93
FF2	1.0	1.0	1.0	0.76	0.77	1.0	1.0	1.0	1.0	0.94
SFW	1.0	0.67	1.0	1.0	0.83	0.96	1.0	0.95	1.0	0.92
CFW	1.0	0.89	1.0	1.0	0.58	0.71	1.0	0.9	1.0	0.88
BMW	0.98	0.26	0.41	0.43	1.0	0.01	0.49	0.37	0.58	0.33
DFW	0.61	0.39	0.45	0.51	1.0	0.24	0.54	0.42	0.61	0.49
GW	1.0	0.56	0.96	0.91	1.0	0.52	1.0	0.7	1.0	0.82
ZP	1.0	0.72	1.0	0.99	0.53	0.90	1.0	1.0	1.0	0.88
DW1	0.51	0.9	0.88	1.0	0.5	0.9	1.0	0.64	1.0	0.79
DW2	0.54	0.74	1.0	1.0	0.89	0.8	1.0	0.72	1.0	0.84
Fish Meal	1.0	0.99	1.0	0.98	0.98	0.88	1.0	0.87	1.0	0.96

Table 6.12: A/E ratio of essential amino acids in waste products to that of shortfin eel (Aa/AA) and Essential Amino Acid Index (EAAI)
Aa= A/E ratio of the waste product; AA = A/E ratio of the fish carcass.

Waste Product **<u>Shortfin eel</u>**	**Arginine**	**Histidine**	**Isoleucin e**	**Leucine**	**Lysine**	**Methionin e**	**Phenylal.**	**Threonine**	**Valine**	**EAAI**
TO	1.0	0.56	1.0	1.0	0.69	1.0	1.0	1.0	1.0	0.89
CO	1.0	0.64	1.0	1.0	0.6	1.0	1.0	1.0	1.0	0.89
CR	0.96	0.75	1.0	1.0	0.47	1.0	1.0	1.0	1.0	0.88
S G	1.0	0.73	1.0	0.91	0.54	1.0	1.0	1.0	1.0	0.89
FV	0.97	0.68	1.0	0.98	0.73	1.0	1.0	1.0	1.0	0.92
FF1	1.0	0.9	1.0	0.71	0.75	1.0	1.0	1.0	1.0	0.92
FF2	1.0	0.95	1.0	0.74	0.76	1.0	1.0	1.0	1.0	0.93
SFW	0.99	0.58	1.0	1.0	0.82	1.0	1.0	1.0	1.0	0.92
CFW	1.0	0.77	1.0	1.0	0.57	0.83	1.0	1.0	1.0	0.89
BMW	0.92	0.22	0.38	0.42	1.0	0.01	0.5	0.41	0.57	0.32
DFW	0.57	0.34	0.42	0.49	1.0	0.28	0.56	0.46	0.6	0.49
GW	0.97	0.48	0.91	0.88	1.0	0.61	1.0	0.78	1.0	0.82
ZP	1.0	0.63	1.0	0.96	0.52	1.0	1.0	1.0	1.0	0.88
DW1	0.48	0.78	0.83	1.0	0.49	1.0	1.0	0.71	1.0	0.78
DW2	0.51	0.64	1.0	1.0	0.88	0.93	1.0	0.8	1.0	0.84
Fish Meal	0.99	0.85	1.0	0.95	0.97	1.0	1.0	0.97	1.0	0.97

Table 6.13: The mean individual fatty acids in mg mg^{-1} of sample (±se) of the waste products and fish meal.

Fatty acids	TO	CO	CR	SG	FV	FF1	FF2	SFW	CFW	BMW	DFW	GW	ZP	DW1	DW2	T.oil	FM
14:0	11.16 ±0.6	1.51 ±0.1	0.64 ±0.0	1.74 ±0.1	7.01 ±0.2	9.25 ±0.3	5.6 ±0.2	0.54 ±0.0	1.71 ±0.01	3.28 ±0.01	1.44 ±0.01	3.99 ±0.02	1.92 ±0.05	1.0 ±0.0	19.61 ±0.02	18.87 ±1.3	3.64 ±0.0
16:0	108.30 ±6.5	22.94 ±1.8	19.40 ±0.17	6.73 ±0.4	40.33 ±0.9	49.54 ±2.0	38.97 ±1.8	10.83 ±0.3	37.76 ±0.1	55.17 ±0.3	39.19 ±0.2	70.25 ±0.2	13.96 ±0.3	5.19 ±0.02	83.41 ±0.2	168.34 ±12.0	22.59 ±0.2
18:0	32.07 ±1.9	7.45 ±0.6	4.96 ±0.0	2.53 ±0.17	24.0 ±0.73	26.92 ±0.9	11.01 ±0.58	3.80 ±0.1	23.40 ±0.04	45.97 ±0.25	16.72 ±0.07	48.35 ±0.12	4.32 ±0.14	1.83 ±0.0	38.89 ±0.12	47.59 ±3.36	4.12 ±0.0
20:0	1.12 ±0.1	0.14 ±0.0	nd	0.11 ±0.02	0.56 ±0.03	0.77 ±0.0	0.45 ±0.03	0.99 ±0.0	0.32 ±0.0	0.40 ±0.01	0.22 ±0.01	0.64 ±0.01	0.13 ±0.02	nd	0.59 ±0.02	1.74 ±0.12	0.19 ±0.0
22:0	0.33 ±0.0	nd	nd	nd	0.44 ±0.0	0.47 ±0.0	0.22 ±0.0	0.48 ±0.0	0.15 ±0.01	Nd	0.11 ±0.0	0.29 ±0.02	nd	nd	0.15 ±0.01	0.85 ±0.08	Nd
å SAT	**152.99 ±9.2**	**32.05 ±2.5**	**25.04 ±0.2**	**11.17 ±0.7**	**72.36 ±2.0**	**86.97 ±3.3**	**56.29 ±2.6**	**16.65 ±0.5**	**63.37 ±0.1**	**104.88 ±0.6**	**57.69 ±0.3**	**123.55 ±0.4**	**20.44 ±0.5**	**8.08 ±0.0**	**142.66 ±0.3**	**237.40 ±16.9**	**30.57 ±0.2**
16:1n-7	30.12 ±1.7	8.16 ±0.6	4.88 ±0.0	3.15 ±0.2	18.43 0.4±	25.10 ±0.9	11.25 ±0.5	0.70 ±0.0	5.49 ±0.05	4.45 ±0.04	7.91 ±0.05	9.79 ±0.04	4.43 ±0.05	0.24 ±0.0	3.99 ±0.2	53.72 ±3.8	7.06 ±0.1
18:1n-9	171.7 ±9.7	20.92 ±1.5	15.63 ±0.1	0.93 ±0.06	34.64 ±0.7	45.01 ±1.7	33.15 ±1.4	57.38 ±1.7	50.96 ±0.2	66.29 ±0.3	59.47 ±0.2	97.67 ±0.2	5.16 ±0.1	2.99 ±0.0	53.46 ±0.3	294.84 ±21.2	13.02 ±0.1
18:1n-7	15.73 ±0.9	5.32 ±0.4	4.03 ±0.0	1.26 ±0.08	7.22 ±0.1	8.09 ±0.3	5.47 ±0.2	2.91 ±0.1	3.53 ±0.01	5.1 ±0.04	3.21 ±0.02	7.21 ±0.07	3.85 ±0.08	0.33 ±0.0	10.84 ±0.1	26.41 ±1.8	2.61 ±0.0
20:1n-9	27.7 ±1.7	2.75 ±0.2	1.26 ±0.0	0.34 ±0.01	2.75 ±0.08	3.20 ±0.1	3.51 ±0.3	4.54 ±0.1	0.6 ±0.01	1.3 ±0.1	1.12 ±0.02	0.77 ±0.07	nd	nd	1.07 ±0.1	47.14 ±3.2	1.99 ±0.1
å MONO	**249.38 ±14.4**	**37.29 ±2.7**	**25.84 ±0.1**	**5.71 ±0.4**	**65.52 ±1.4**	**84.48 ±3.2**	**54.01 ±2.6**	**65.98 ±1.7**	**60.85 ±0.3**	**77.15 ±0.3**	**72.12 ±0.2**	**115.9 ±0.2**	**13.57 ±0.2**	**3.62 ±0.0**	**69.61 ±0.5**	**428.3 ±30.6**	**24.97 ±0.2**
18:2n-6	39.91 ±1.9	1.65 ±0.1	0.76 ±0.0	0.65 ±0.04	0.95 ±0.01	1.05 ±0.0	1.25 ±0.09	4.95 ±0.1	12.60 ±0.1	1.76 ±0.09	5.61 ±0.01	24.23 ±0.1	8.73 ±0.1	0.34 ±0.01	4.27 ±0.07	87.94 ±6.1	0.77 ±0.0
18:3n-3	3.77 ±0.1	1.09 ±1.8	0.45 ±0.0	0.67 ±0.05	0.51 ±0.0	0.57 ±0.0	0.46 ±0.07	2.63 ±0.1	1.11 ±0.06	0.29 ±0.01	0.38 ±0.02	1.84 ±0.05	19.9 ±0.3	0.17 ±0.01	1.0 ±0.02	10.53 ±0.9	0.48 ±0.0
18:3n-6	1.12 ±0.1	0.42 ±0.02	0.25 ±0.0	0.15 ±0.01	0.76 ±0.01	1.04 ±0.0	0.38 ±0.03	nd	0.26 ±0.0	0.52 ±0.07	0.20 ±0.0	0.64 ±0.0	1.23 ±0.01	nd	0.49 ±0.04	2.13 ±0.1	0.24 ±0.0
18:4n-3	0.48 ±0.1	0.17 ±0.0	0.15 ±0.0	1.63 ±0.1	0.59 ±0.3	0.69 ±0.2	nd	0.31 ±0.1	nd	0.10 ±0.0	0.33 ±0.08	0.43 ±0.0	0.92 ±0.02	0.16 ±0.0	0.86 ±0.1	6.33 ±0.3	2.98 ±0.0
20:2n-6	3.16 ±0.1	1.0 ±0.08	0.46 ±0.01	0.22 ±0.01	1.14 ±0.02	1.44 ±0.1	0.19 ±0.01	nd	0.30 ±0.01	Nd	nd	0.17 ±0.04	0.34 ±0.0	nd	nd	6.81 ±0.7	nd
20:3n-3	0.58 ±0.1	0.39 ±0.06	0.21 ±0.0	0.13 ±0.0	0.33 ±0.03	0.42 ±0.0	ng	nd	nd	Nd	nd	nd	0.34 ±0.08	nd	nd	1.59 ±0.1	nd
20:3n-6	0.93 ±0.1	0.43 ±0.01	0.25 ±0.0	0.15 ±0.01	0.36 ±0.02	0.48 ±0.0	nd	nd	0.45 ±0.01	Nd	nd	0.25 ±0.0	0.30 ±0.02	nd	nd	2.25 ±0.1	nd

20:4n-6	2.06 ±0.1	6.65 ±0.6	4.28 ±0.02	0.89 ±0.07	10.77 ±0.2	11.73 ±0.4	0.25 ±0.02	nd	2.53 ±0.0	Nd	nd	0.76 ±0.01	3.66 ±0.06	nd	nd	5.24 ±0.6	0.34 ±0.0
20:5n-3	6.68 ±0.1	5.10 ±0.3	2.74 ±0.06	9.03 ±0.7	22.0 ±0.8	29.4 ±0.8	0.87 ±0.04	0.21 ±0.0	0.38 ±0.08	Nd	0.13 ±0.03	0.38 ±0.05	5.23 ±0.08	nd	nd	25.97 ±1.8	16.63 ±0.1

Table 6.13 (Cont'd): The mean individual fatty acids in mg mg^{-1} of sample (±se) of the waste products and fish meal.

Fatty acids	**TO**	**CO**	**CR**	**SG**	**FV**	**FF1**	**FF2**	**SFW**	**CFW**	**BMW**	**DFW**	**GW**	**ZP**	**DW1**	**DW2**	**T.oil**	**FM**
22:4n-6	0.42 ±0.1	8.29 ±0.9	2.02 ±0.0	1.10 ±0.07	1.26 ±0.03	1.36 ±0.0	nd	nd	0.27 ±0.0	Nd	nd	0.11 ±0.02	nd	nd	0.2 ±0.03	1.12 ±0.09	nd
22:5n-3	2.31 ±0.0	2.92 ±0.2	1.38 ±0.0	0.27 ±0.02	3.46 ±0.08	3.36 ±0.1	0.24 ±0.03	nd	0.50 ±0.01	Nd	nd	0.65 ±0.01	nd	nd	0.31 ±0.02	9.15 ±0.7	2.2 ±0.1
22:6n-3	22.61 ±0.4	17.58 ±1.3	15.19 ±0.1	5.32 ±0.4	9.98 ±0.1	8.55 ±0.2	2.27 ±0.09	1.45 ±0.0	0.28 ±0.05	0.47 ±0.02	0.40 ±0.06	0.35 ±0.03	0.23 ±0.02	nd	0.53 ±0.06	82.45 ±5.8	9.62 ±0.1
å **n-3**	**36.46 ±0.3**	**27.26 ±2.0**	**20.1 ±0.2**	**17.06 ±1.2**	**36.96 ±1.4**	**43.00 ±0.8**	**3.97 ±0.1**	**4.73 ±0.1**	**2.42 ±0.1**	**0.86 ±0.08**	**1.25 ±0.1**	**3.69 ±0.1**	**26.73 ±0.4**	**0.40 ±0.0**	**2.71 ±0.1**	**136.0 ±9.6**	**31.96 ±0.4**
å **n-6**	**47.90 ±2.2**	**18.58 ±1.8**	**8.15 ±0.0**	**3.20 ±0.2**	**15.31 ±0.38**	**17.11 ±0.6**	**2.29 ±0.1**	**5.12 ±0.1**	**16.5 ±0.09**	**2.31 ±0.1**	**5.92 ±0.0**	**26.3 ±0.2**	**14.4 ±0.2**	**0.4 ±0.0**	**5.2 ±0.07**	**105.8 ±7.8**	**1.49 ±0.0**
å **PUFA**	**84.36 ±2.6**	**45.84 ±3.8**	**28.31 ±0.2**	**20.2 ±1.4**	**52.28 ±1.8**	**60.12 ±1.4**	**6.27 ±0.3**	**9.85 ±0.2**	**18.93 ±0.2**	**3.18 ±0.2**	**7.1 ±0.1**	**30.0 ±0.2**	**41.15 ±0.7**	**0.81 ±0.0**	**7.92 ±0.1**	**241.85 ±17.5**	**33.45 ±0.4**

Table 6.14: The mean P (%), Ca (ppm), Cu(ppm), Zn(ppm), Fe(ppm) and K(ppm), content of waste products and fish meal.

Parameter	**TO**	**CO**	**CR**	**SG**	**FV**	**FF1**	**FF2**	**SFW**	**CFW**	**BMW**	**DFW**	**GW**	**ZP**	**DW1**	**DW2**	**FM**
P (%)	0.68	1.4	0.98	0.47	0.60	1.59	2.86	0.10	1.16	6.22	2.56	1.16	1.39	0.28	1.07	2.20
Ca (ppm)	3100	2000	960	39000	24000	28000	52000	880	19000	130000	47000	24000	750	124	3900	30000
Cu (ppm)	30	10	< 2	2	2	< 2	< 2	5	14	< 2	3	10	13	< 2	5	5
Zn (ppm)	260	480	280	40	320	67	52	64	160	68	68	340	76	24	23	66
Fe (ppm)	260	840	240	3100	510	39	36	570	750	41	890	2000	410	10	-	290
K (ppm)	3120	10490	7130	8190	7140	6640	9060	90	2220	1260	12500	1100	7400	30	340	8470

7 Discussion

7.1 Industry Audit

The audit of the seafood processing industry in Victoria revealed that the wastes available in the largest quantities were marine finfish (including shark) with an estimated 4,260 tonnes of waste of this type recorded in the audit (Table 6.4). These wastes were readily available for value-adding and are currently disposed of mainly by commercial disposal companies or to landfill. Approximately 50% of these wastes are currently produced by the MWFM and there are a number of processing companies nearby which also produce significant quantities of waste. In addition, sources at the MWFM estimates that the waste could be doubled (to 4,000-5,000 tonnes per annum) if small/medium sized customers were encouraged to return their wastes to a central location on a daily basis.

Outside of the CBD, the major waste producing centres were Geelong, Lakes Entrance and Portland and consideration should be given to siting regional processing plants in each of these three centres to retain freshness and maximise the efficiency with which the wastes can be processed into good quality fishmeal. Positioning processing plants near to the sources of waste (*i.e* MWFM and major fishing ports) will reduce transport and storage costs for the raw ingredients and facilitate the use of by-catch as a replacement for fishmeal. The developing coastal aquaculture industry in Victoria is a potential lucrative market for the fish meal produced at these coastal processing plants and a reliable supply of cost-effective, good quality fishmeal will underpin the growth of this industry.

In summary, current waste disposal practices in Victoria are inherently expensive for the industry and offer many opportunities for downstream value-adding which can both offest existing disposal costs and potentially provide a secondary income stream and additional employment through value-adding.

7.2 Chemical Analysis

The suitability of ingredients for inclusion in fish diets is based on its chemical composition, an assessment of digestibility, and the potential maximum level of incorporation in diets, the latter of which is determined by the growth response to experimental diets with the ingredient. In addition, other commercial considerations such as cost, regularity/ availability of supplies, shelf-life, effects on palatability/ texture and many other criteria also need to be taken into account when a new ingredient is to be incorporated into an aquafeed.

Fishmeal is considered to be an ideal ingredient for fish feeds in view of its palatability, high and easily digestible protein content, the correct amino acid balance, and the presence of essential fatty acids. In addition, it is also thought that fishmeal has hitherto unidentified growth promoting factors. On the other hand, fishmeal is relatively expensive (about US $420 t^{-1} in December 2000 for Peruvian fishmeal, standard FOB, Peru; Anonymous, 2000), and its supplies can also be irregular. Furthermore, increased concern is being expressed over the sustainability of fish meal supplies considering the large tonnage of raw fish, obtained almost exclusively from the marine capture fisheries, used for fishmeal manufacture (Naylor *et al.*, 2000). Specifically, concern is being expressed over the status of such fisheries and the fact that such a large tonnage is not made available for direct human consumption, particularly in developing countries. Such arguments, however, are not always necessarily factually correct and/or convincing (Pike, 2000), but nor should they be ignored. Indeed, much progress has been made on identifying alternative protein sources over the last two decades or so (Hardy, 1996). However, most of the research on alternatives for fishmeal has been based on evaluating agricultural by-products and only limited exploratory research has been done on the type of waste product investigated in the present study. A summary of the former is given by Tacon (1987).

Any ingredient which has the potential to replace fishmeal in aquafeeds, either partially or wholly, must foremost have an amino acid profile close to that of fishmeal. A number of authors have reported that the body EAA composition of target aquaculture species reflects its requirements for the EAAs. Based on this similarity, many authors have utilised the A/ E ratios, combined with experimental determinations, to estimate the EAA requirements of a number of fish species for aquaculture (Arai 1981; Tacon and Cowey, 1985; Wilson and Poe, 1985; Moon and Gatlin, 1991; Ng and Hung, 1994; Ngamsnae et al., 1999). Mambrini and Kaushik (1995) on the other hand (based on an extensive review of the literature on EAA requirements and methods used in estimations) concluded that carcass amino acid profile best reflects the ideal pattern of a reference protein, and that it can be used as a guideline for formulating aquafeeds or for studying EAA requirements for such feeds. In the present study the amino acid profile of the ingredients was compared with that of each of the whole body tissue of the three fish species under consideration, as well as with that of fishmeal, using A/ E ratios as well as the EAAI.

It is also important to note that a high protein content and/or a high TAA and/or EAA in an ingredient does not necessarily mean it has the ability to fulfil the potential amino acid requirements. This is exemplified in the case of CR and CO; these waste products had relatively high protein content (60.7±0.2 and 67.3 ±0.3%, respectively) and high TAA and EAA content comparable to that of fishmeal (66.5±0.3%). However, their A/E ratios were not very complementary to those of the whole body tissue of the three fish species studied, as opposed to FV which had a lower protein content (42.9±0.02%), but had the most complementary A/E ratio and EAAI to that of whole body tissue of the fish species. Zooplankton on the other hand had a relatively high protein content (62.5±0.02 %) but had a low amount of EAA (896 μ moles g^{-1}), and therefore is unlikely to be useful as a fishmeal replacement in aquafeeds. Waste products such as BMW and DFW appeared to have the lowest complementarity (based on EAAI) to fishmeal and whole body tissue of the three fish species, indicating that these waste products are unlikely/or to be of very limited use in aquafeeds as a fishmeal replacement.

It is accepted that fishmeal represents one of the best, if not the best, source of fatty acids for both marine and freshwater species. If the amounts of PUFA, HUFA and n3 : n6 ratio, and the concentrations of individual fatty acids (such as arachidonic acid- 20:4n-6, eicosapentaenoic acid- 20:5n-3, docosapentaenoic acid- 22:5n-3 and docosahexonic acid- 22:6n-3), all indices of nutritional importance for marine fish (Sargent *et al.*, 1999), as well as linoleic acid- 18:2n-6 and linolenic acid 18:3n-3, often required by freshwater fish (Bell *et al.*, 1986; Sargent *et al.*, 1995), of the waste products are taken in to consideration CO, CR, TO, FV and FF1 could be considered to be superior to fishmeal. The exception may be in the n3: n6 ratio.

ZP contained the highest amount of 18:3n-3 (19.9±0.3 μg mg^{-1}) of all waste products analysed, and generally had a favourable fatty acid profile in regard to its use as a potential source of fatty acid in aquafeeds. Accordingly, it will be of interest to explore the potential use of these waste products as essential fatty acid sources through a series of growth experiments both on selected freshwater and marine cultured finfish species. In this regard the effectiveness of carp roe as a weaning food for Australian shortfin glass eels (De Silva *et al.*, 2001) and on gonadal differentiation of European eel (Grandi *et al.*, 2000) is noteworthy.

The study emphasises the need to have a multi-prong approach to determine the suitability of ingredients for incorporation into fish feeds. The results suggest that a considerable number of aquatic food industry wastes in Victoria and indeed other seafood industry centres, has the potential to be used in aquafeeds, not always necessarily as fishmeal replacement but also as a source of essential fatty acids. In all cases however, the findings have to be confirmed through growth trials, the step prior to possible commercialisation.

7.3 Digestibility Trials

The digestibility trials were conducted as specified in the project agreement, however the results were not satisfactory and will be reported as an addendum to this report.

8 Benefits

There are three industrial sectors which will directly benefit from the use of "wastes" in aquafeed development, *vis:*

- Seafood processing and marine fishing industry.
- Aquafeed manufacturing industry.
- Australian aquaculture industry.

8.1 Seafood Processing and Marine Fishing Industry

The seafood processing industry has been a key driver of this project since its inception due to the volume of waste generated by that sector and the inherent problems and costs of its disposal. The use of the wastes for aquafeed production will provide major economic savings to this industry through:

- Eliminating and/or offsetting disposal costs
- Adding value to existing production by "selling" wastes.

This study has demonstrated that there is seafood processing waste of sufficient quality and quantity in Victoria (approx 5,000 tonnes per annum) to contribute significantly to the replacement of fish meal in aquafeeds. However, if the venture is to be technically viable the supply of wastes must be reliable and the quality must be consistent. This is an important factor in the re-utilisation of the product for aquafeeds as marine carnivorous fish intensively reared are more sensitive to fishmeal quality than most land animals (Pike, 1999). The inclusion of by-catch in aquafeeds would considerably increase the quantity of seafood waste available for the replacement of fishmeal and the reliability of supply would also be more predictable.

The main aspects of quality control to be considered are (after Pike, 1999):

- Raw material type (whole fish or trimmings).
- Freshness of raw material.
- Processing temperature exposure.
- Lipid quality
- Microbiological standards. Pasteurisation may need to be undertaken to ensure there is no transfer of disease from waste products to aquaculture species. Although there is a relatively low "real" risk of disease transmission to aquaculture species (as conventional processing will sanitise the wastes) there

may be a perceived risk among the public in relation to the issues raised by the BSE epidemic in European cattle. This will be investigated further in Phase II of the project.

Assuming that a constant supply of suitable waste can be maintained, consistent product quality can be achieved through siting the aquafeed plant close to the supply of wastes to minimise the chances of degradation. Methods of handling the wastes from catch to disposal would have to be standardised to maintain product quality and wastes may have to be refrigerated and/or otherwise stabilised at the point of processing. The economic viability of these plants will depend largely on the cost of production of the waste-product fishmeal compared with conventional imported fishmeal. The cost of production will depend on the extent of processing required to formulate the aquafeeds, there are two options:

- Direct inclusion into aquafeeds. This option involves minimal pre-processing of the wastes (*e.g.* mincing or de-watering) prior to inclusion in aquafeeds as used in a recent study which recycled trout offal into aquafeeds (Ingram, 1999). In this process the moisture content and associated pre-processing requirements to get the waste to a consistent texture before extrusion into food will be a limiting factor (most extruders can handle about 30% moisture content max.). However, even if the FCR's for a higher moisture content feed are not as good as conventional feeds the cheaper cost of ingredients should compensate.
- Rendering wastes to make fishmeal. If this option is taken then there is also the possibility of extracting fish oil from the wastes which is another major cost item in aquafeeds.

Locating the rendering plants close to where the wastes are produced will reduce transport costs and increase the quality of the final product. The subsequent economic viability of utilising the fishmeal produced from the rendered fish wastes for aquafeeds requires further work. Trial aquafeeds must be formulated using the waste products and trialed at a commercial scale for selected aquaculture species. The economics of the venture can then be thoroughly assessed and investment undertaken

8.2 Aquafeed Manufacturing Industry

The Australian aquafeed manufacturing industry is totally reliant on imported fishmeal and is thus vulnerable to fluctuations in the supply and price of this commodity on the global market. The aquafeed manufacturing industry will benefit from this project as, if commercialised, they will have ready access to a locally produced, consistent quality fishmeal replacement.

Globally, there is a total annual production of around 6.5 million tonnes fish meal and 1.3 million tonnes fish oil (www.infoma.com). The poultry and swine industry are the world's largest consumers of fish meal (66%), followed by the dairy and beef industry (27%) and aquaculture (4%) (Gill, 1997). The supply of "industrial" fish for fish meal varies depending on global climatic trends, notably the "El Nino" phenomenon in the Pacific Ocean (FAO, 1995). Chile and Peru supply around 80% of the world's fish meal (www.infoma.com) and in 1998/99, global production of fish meal fell to 4.7 million tonnes (average 6.7 million tonnes) due to the disastrous effect of El Nino on pelagic fish supplies in these countries. During these years, fishmeals and oils are in short supply and the price will inevitably rise.

The quantity of fishmeal imported into Australia has increased steadily from 19,297 tonnes in 1990/91 (worth >$9.5 million) to 27,000 tonnes worth >$17.5 million in 1998 (www.abareconomics.com.au).

8.3 Aquaculture Industry In Australia

The aquaculture industry in Australia will benefit from this project through the availability of locally-produced, cost-effective diets which are specifically formulated for the target aquaculture species. In turn they will reduce their reliance on imported aquafeeds.

The International Fishmeal and Oil Manufacturers Association (IFOMA) predicts that compound feeds for the global aquaculture industry will require around 2.8 million tonnes of fishmeal and 0.9 million tonnes of oils by the year 2010 (Pike and Barlow, 1999). Similarly, FAO has indicated that the demand for fish feed would increase by 240% over the next ten years, but supply of fishmeal can only increase by 150% due to declining fish stocks (Holmyard, 2001). There is clearly a shortfall in the supply of adequate fish meal for the aquaculture industry. A recent study has evaluated the current requirements of the Australian aquaculture industry for aquafeeds (Table 8.1) as 20,402 tonnes per annum.

Table 8.1 Australian aquaculture production and aquafeed requirements, 1997/98 (Allan *et al* 1999).

Species Groups	Production (tonnes)	% Produced using Aquafeeds	Assumed FCR	Aquafeed Requirement (t)
Non-feeding molluscs	10,624	0	-	-
Freshwater crayfish	279	30	2.0	167
Jumbo tiger prawn	1,277	100	2.0	2,554
Japanese tiger prawn	287	100	2.0	574
Atlantic salmon	7,068	100	1.5	10,602
Rainbow trout	3,001	100	1.5	4,502
Other salmonids	10	100	1.5	15
Southern bluefin tuna	2,089	0	-	-
Barramundi	496	100	2.0	992
Silver perch	135	100	2.0	270
Eels	350	100	2.0	700

Other natives	13	100	2.0	26
Crocodiles	38	0	-	-
TOTAL	**25,667**			**20,402**

If we assume that aquaculture production will continue to increase moderately (10%) over the next 10 years, this would be equivalent to a demand for aquafeeds of approximately 67,000 tonnes in 2010. This would be an increase in demand of 328% for aquafeeds. Assuming an inclusion rate of 50% fishmeal in aquafeeds, this would translate to an additional demand of 23,000 tonnes of fishmeal by the Australian aquaculture industry by 2010. Alternatives to conventional fishmeal clearly have to be found if growth in the Australian aquaculture industry is not to be constrained by lack of cost-effective aquafeeds.

The results of this project, if commercialised, will also have the following benefits for the aquaculture industry:

1. There will be an opportunity for fish farmers to manufacture their own extruded feeds utilising locally available wastes.
2. Increased flexibility of being able to produce small volumes of “specialised” feeds for new and developing species which major aquafeed manufacturers cannot/ will not supply.
3. The Southern Bluefin Tuna Industry (SBT) currently uses no fishmeal or extruded aquafeeds and FCRs for SBT fed on imported pilchards is unacceptably high (around 15:1) (Napier, 1999). The development of extruded compound feeds incorporating relatively cheap “fishmeal replaced”-type ingredients is a requirement of industry.

9 Further Development

This one-year project has essentially been a feasibility study to make a preliminary estimate of the quantity of waste available in Victoria and its suitability as a fishmeal replacement in aquafeeds. A proposal has been submitted to FRDC which will pilot the concept through the preparation and testing of formulated feeds using the waste sources that have been identified. This new project (Phase II) will also involve a more complete market analysis of experimental feeds in terms of potential market demand and associated costing structure.

The specific outcomes of the proposed project are:

- Establishment of “waste” incorporated aquafeed formulations for selected commercial aquaculture species.
- Realisation of the potential for increased value of existing fisheries and aquatic resource “waste” products.
- Projected economic and environmental benefits of reduced seafood waste disposal and use of naturally produced aquatic resources (*e.g.* commercial fisheries by-catch) as key ingredients in formulated aquafeeds.
- Estimation of economics of alternative cost-effective supply of locally produced species-formulated aquafeeds.
- Performance database (specific growth rates, feed conversion ratios, cost-benefit analysis *etc*.) for waste incorporated aquafeeds.

The proposed project will complement a number of linked projects investigating various aspects of aquafeed development from solid wastes and the utilisation of by-catch from commercial trawl fisheries. It is intended that the outcomes of the Phase II project will lead directly to commercialisation of the concept.

10 Conclusion

This study has shown that there is currently a significant quantity of seafood processing, food processing and aquatic waste available in Victoria which has potential to be value-added rather than utilising conventional disposal methods. The suitability of the samples collected for inclusion in fish diets was evaluated based on the chemical composition and the results demonstrated the wastes most suitable for use as a fishmeal replacement were those which contained a high proportion of finfish (including shark) wastes. Other samples had potential for incorporation into feeds as mineral supplements or additives *e.g.* plankton, but were not suitable as a fishmeal replacement.

There were significant quantities of finfish wastes generated on a regular basis in Victoria, particularly in the Melbourne-Geelong area and it was estimated that the current waste production of the MWFM could be doubled if small buyers were encouraged to return their wastes to a central facility. The quantity of wastes in the Portland and Lakes Entrance areas was significantly smaller, but could be supplemented by by-catch due to the proximity of a number of fishing ports. Indeed, by-catch is a significant potential future source of raw product for this industry and links have been developed during this projects with other FRDC projects investigating ways of value-adding by-catch.

The study emphasised the need for a multi-pronged approach to determine the suitability of ingredients for incorporation into fish diets. In all cases, the findings have to be confirmed through growth trials, prior to possible commercialisation.

The economic feasibility of the concept of utilising seafood processing waste as a fishmeal replacement in aquafeeds relates to the:

- market for aquafeed in Australia and overseas;
- the reliability of supply of the wastes;
- price for fish meal world-wide; and
- the cost of technology/ plant to process the waste whether into fishmeal first or by direct inclusion in the aquafeed extrusion line.

Other considerations include the shelf-life, effects on palatability, sanitary status and many other criteria which need to be taken into account when a new ingredient is to be incorporated into a feed.

In conclusion, the utilisation of seafood processing wastes as a replacement for fishmeal in aquafeeds offers considerable potential benefits to the seafood processing industry, the developing aquaculture industry and aquafeed manufacturers in Victoria and elsewhere in

Australia. To capitalise on this potential, however, more research is needed to overcome technical and logistical difficulties associated with converting the raw product to good quality fishmeal and/or aquafeeds.

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13 APPENDIX 1: INTELLECTUAL PROPERTY

Intellectual property generated from this project is primarily in the form of research information, including:

- Database development for seafood processors in Victoria.
- Techniques for assessing the suitability of wastes for aquafeeds.

14 APPENDIX 2: STAFF EMPLOYED ON THE PROJECT

Name	Organisation	% Time
Geoff Gooley	MAFRI	5
Fiona Gavine	MAFRI	20
Sena de Silva	Deakin University	5
Rasanthi Gunasekera	Deakin University	60