FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

New Opportunities for Seafood Processing Waste

Appendix 1: Literature Review

Dr Janet Howieson

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CESSH
CENTRE OF EXCELLENCE SCIENCE SEAFOOD HEALTH

AUSTRALIAN SEAFOOD COOPERATIVE RESEARCH CENTRE

WAFIC
WESTERN AUSTRALIAN FISHING INDUSTRY COUNCIL INC

LITERATURE REVIEW (ONGOING)

SEAFOOD PROCESSING WASTE OPTIONS

1. Introduction

In many seafood markets, particularly in developed countries there is a trend towards processing early in the supply chain to produce a “convenient” seafood fillet/seafood product that does not require further processing following purchase (Olsen et al., 2007). Such processing produces by-products, potentially available for alternate uses. It is estimated that the Australian fishing industry produces in excess of 20,000t of seafood processing waste per year (Knuckey, Sinclair, Surapaneni, & Ashcroft, 2004b). In finfish the fillet yield when processing is species dependent and is often in the range of 30-50% (Rustad et al., 2011). One study (Ng, 2010) examined the finfish waste streams for 5 different commercially caught Australian fish species. Crimson snapper was found to have a total waste of 59%, blue spot emperor a total waste of 71%, saddletail snapper a total waste of 69%, painted sweetlip bream a total waste of 56% and thickskin shark a total waste of 40%. The breakdown of the waste can be seen in Table 1.

Table 1: Waste produced from five commercially caught Australian fish species

	Fillet	Heads	Frames	Skins	Viscera
Crimson snapper	41%	31%	16%	5%	7%
Blue spot emperor	29%	42%	18%	7%	4%
Painted sweetlip bream	44%	28%	15%	6%	7%
Saddletail snapper	33%	32%	14%	13%	8%

Atlantic salmon also is an interesting case study: Liaset et al. (2003) found that much of the salmon are sold to the customer as gutted, whole salmon, but significant amounts also are sold as fillets. In a typical automated filleting line, the fillets count for approximately 59-63% of the total wet weight in a salmon with body weight of 5-6 kg. Other by-products from the filleting line are salmon frame (9-15%), head (10-12%) and trimmings (1-2%) (Liaset et al. 2003). There is the opportunity for salmon eggs can be processed into caviar, used as fish bait, or as a raw material for the production of cholesterol, lipids and proteins (Ockerman and Hansen 2000).

The non-edible portions of a number of other common seafood species are shown in Figures 1 (crustacean, shellfish and cephalopods) and 2 (Finfish).

Traditionally seafood by-products were considered to be of low value or as a problem and were used as feed for farmed animals, as fertilisers or discarded. However, more recently due to environmental issues and the increased cost of disposal, other waste utilisation options are being considered. When reviewing utilisation options for seafood waste it is important to

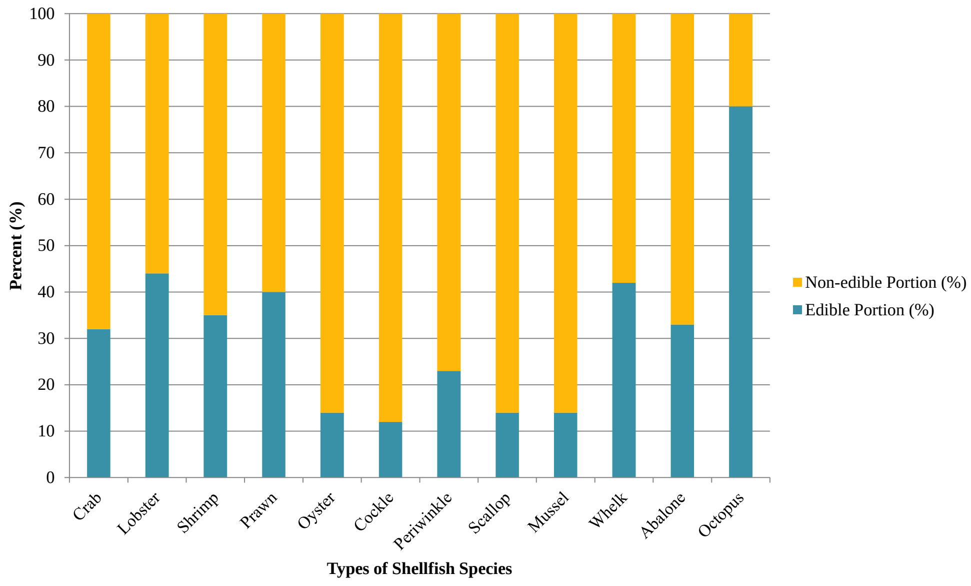

Figure 1: Edible v non-edible portions of common crustacean, shellfish and cephalopods.

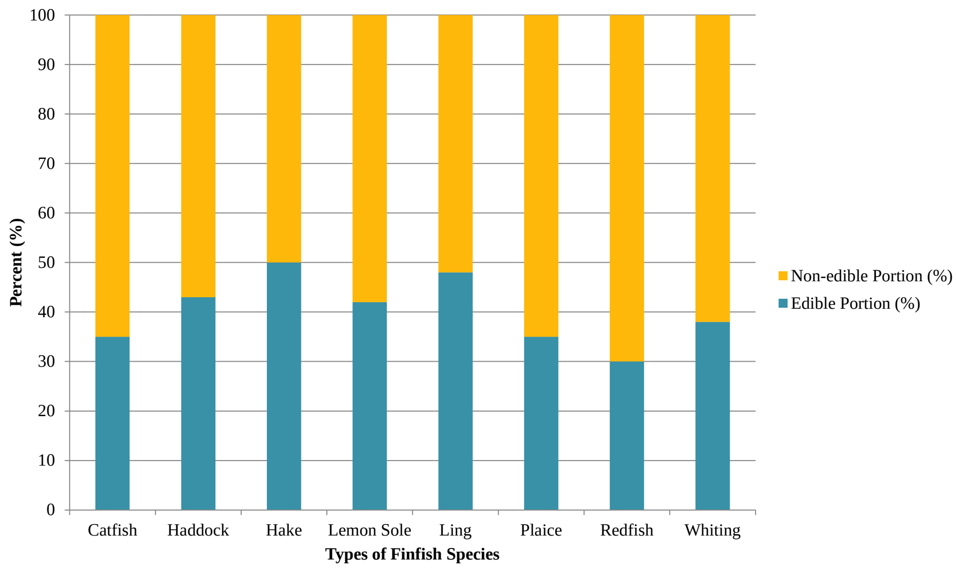

Figure 1: Edible v non-edible portions of common shellfish.

remember that technical feasibility does not always translate to economic feasibility. Due to

the rapid deterioration associated with seafood by-products, some aspects a seafood processor must consider before committing to a specific waste utilisation process include; handling, sorting and storage systems on board fishing vessels that process at sea, and means to transport by-products from the vessel to the processing plants, safe and cost effective preservation methods, volume and schedule of availability of the by- product and distance from processing site to market and associated transport costs (Marsh & Bechtel, 2012).

A study performed by (Archer, Watson, Garrett, & Large, 2005) highlighted several waste management options available. The overall environmental impact scores for the different seafood waste management options were calculated and each option was assessed for its impact on noise, odour, transport distance, solid and liquid waste production, energy and water use, space requirements and airborne pollution. Each component was marked 0 to 2, with a higher score suggesting a higher environmental impact. The results are displayed in Table 2 below.

Table 2: Waste options assessed for environmental impact scores

Scores	Options
1-4	Heads, tongues, cheeks, fins Mince Roe and milt Direct animal feed Disposal at sea
5-8	Ensiling Landspreading
9-12	Soups, stocks and sauces Composting Aerobic digestion Anaerobic digestion Fertilisers and soil conditioners Fish bones Molluscan shell based products Incineration with energy recovery Biofuels
13-16	Fishmeal and oil Rendering Mechanical and biological treatment Autoclaving Alkaline hydrolysis Incineration Pharmaceuticals Collagen and gelatin Fish protein concentrates Fish protein hydrolysates Enzymes Leather Crustacean based derivatives

Many of the options listed above are providing strategies that can potentially help the Australian fishing industry find alternate ways to address the discarded heads, frames, skin viscera and shell, as opposed to the cost burden experienced now to dispose of it all. This literature review explores some of these options in line with the seafood processing waste utilisation framework developed for Seafood CRC 2013.711.40: New opportunities for Seafood Processing Waste.

This framework is summarised below.

Tier 1: Efficient, Effective and Legal Waste Disposal (no value add product but triple bottom line benefits) (Section 2)

Tier 2: Simple Value Add: fertiliser, fish meal, hydrolysate, feed components (Section 3)
Tier 3: Complex value add: high quality oil, higher quality hydrolysate, pet food (Section 4).
Tier 4: Premium value add: food, extraction for pharmaceutical additives, food additives, (Section 5).

In the CRC project potential industry partners have been asked to review the framework and develop objectives based on the capacity etc of their operation.

2. Tier 1: Efficient, Effective and Legal Waste Disposal

Disposal at sea
Disposal at sea requires approval from the appropriate government offices. To obtain a licence the identification of the disposal sites, identification of the nominated vessel and a description of the type and quantity of seafood must be given to the appropriate authorities (Archer et al., 2005). Disposal at sea does have the potential to have a negative impact on the marine ecosystem if carried out inappropriately. There is the cost of the license as well as the cost of the environmental impact assessment and monitoring needed to obtain the license (Archer et al., 2005). Although this would not take long to establish as a waste option, the legal uncertainties would need to be resolved.

Incineration
Incineration is an approved method of waste utilisation. Seafood waste is combusted in a special combustion plant with additional fuel to ensure that the flue gases achieve the required temperature retention time. Advantages of waste incineration include that the waste is reduced to ash which can then be landfilled or recycled. The high moisture content of the seafood waste will increase the cost of incineration and the high chloride content may also affect being able to meet emission limits (Archer et al., 2005). Costs of setting up an incinerator would also be significant. So although an option, incineration is best used in remote areas where competing methods are not present (Archer et al., 2005).

Incineration with Energy recovery
This form of waste utilisation involves energy recovery from the controlled combustion of waste. During incineration the heat is recovered indirectly through heat transfer into steam or hot water for process, power or district heating. This form of waste utilisation is not considered viable for seafood waste due to its high moisture, low energy content (Archer et al., 2005).

Autoclaving
Autoclaving involves heat treating waste, loaded into an autoclave drum. Once sealed, 140°C steam is injected into the vessel and the pressure is maintained for up to 45 minutes. The autoclave process is effective at killing pathogens and viruses. Small on site processing appears to be feasible using autoclaving as a waste treatment option. However, energy costs as well as hygiene and operating approvals may add significantly to the cost of this option (Archer et al., 2005)

3. Tier 2: Simple Value Add

Waste can be removed from the processor at no cost, however, it is usually removed for a fee. Fish waste has a high organic load and so it is often classified as a certified waste to dispose of at landfill. Dumping the waste at landfill can cost up to $150/ tonne (Knuckey, Sinclair, Surapaneni, & Ashcroft, 2004a) however, there are many options becoming available to help recycle seafood processing waste and value-add.

3.1 Rendering

Rendering involves crushing and grinding animal by-products followed by heat-treatment to reduce the moisture content and kill micro-organisms (Archer et al., 2005). The fat which is separated from the protein is used in animal feeds and various other chemical derivatives. The left over protein is ground into a powder and used in various products. Fishmeal is the most common form of rendering, however, this process may also be made available as a separate waste treatment. Rendering is advantageous because it accepts all categories of waste, it uses proven technology and rendered products are able to be used for other products/ purposes. Some disadvantages of the process include its high capital costs to develop a facility and its high processing costs. The cost of complying with legislation particularly environmental controls has also been flagged as a significant cost (Archer et al., 2005). Currently there is a company in Australia who have further developed their rendering plant , with funding from the Australian government. Seafish Tasmania has upgraded an old rendering plant to accommodate salmon waste and in their first 6 months of exporting have sold approximately $1.3 million of fish meal and fish oil (Department of Economic Development).

3.2 Fishmeal and oil

Fishmeal is a valuable product produced from seafood processing waste. It is a good source of protein and is rich in lysine, methionine and tryptophan, as well as vitamins and minerals (Riverina, 2013). It is noteworthy that the quality of fish meal is determined both by freshness of the raw material used (the species of fish, and whether whole or parts of fish are used) and by the nutrient digestibility due to the different processing conditions for fish meal production (Ockerman and Hansen 2000). Fishmeal production begins with the mincing of fish waste, followed by cooking and pressing. The raw material is heated to between 80-90 °C for 15-20 minutes. Two products are produced from this process, a liquid press water and a pressed solid press cake. The solid particles are removed from the press water before it is centrifuged to separate the oil from the water after which the crude fish oil is then further processed. The press cake is dried and ground to produce fishmeal (Archer et al., 2005). The production of fishmeal uses finfish waste and some shellfish waste. Although shellfish waste is included, the shell is not due to its high levels of grit. Different fish species possess different nutrient levels and so fishmeal can be quite variable in its protein and amino acid levels (Riverina, 2013).

Fishmeal facilities require licensing and approval under environmental protection legislation as well as inspection and approval from the State Veterinary Service (Archer et al., 2005) . The traditional fishmeal and oil production is a multi-step, energy demanding process that requires larger amounts of raw materials over a long period to justify the high operational costs (Naylor et al., 2009). In England, large capacity fishmeal plants processing approximately 50-100 tonnes of raw material per day cost upwards of £8.5 million. Smaller capacity plants of 1-5 tonnes per hour cost between 100,000 and £700,000. Smaller scale plants also experience variation in quality and composition which makes it difficult to achieve market prices. There are several animal feed companies in Australia that supply the agricultural industry. These companies are able to use the fishmeal to supplement some of the feeds for pigs and poultry. Fishmeal plants are a proven technology, which provide revenue for some parts of the finfish and shellfish industry. Small scale plants appear to have limited capacity for development due to high costs, variable raw material and variation in end product quality (Archer et al., 2005).

Fish oil can be used to increase the omega-3 levels in meat and eggs when fed to land animals and is therefore often added to feed. Fish oil can be processed like other oils and will undergo hydrolysis and saponification, hydrogenation, oxidation, sulphation and sulphurization, fractionation, and thickening of the oil with heat (Ockerman and Hansen 2000). Fish oils are also used for human uses such as canning oil used in canned salmon and sardines, margarine production by hydrogenation and production of cooking fats or shortening (Ockerman and Hansen 2000). Fish oils are all used in the medical and animal feed areas for supply of vitamin A and D. Fish oils can also be used in the production of soaps and detergents, paints and varnishes, floor coverings and oil cloths, oiled fabrics, and in the processing of insecticides, alkalized resins, cosmetics, metal, and processed leather (Ockerman and Hansen 2000). A growing market for fish oil supplements for human consumption is also imposing competing demands on the availability of sufficient fish oil supplies from wild caught fisheries.

3.3 Direct animal feed including bait

Bait is a viable waste option which can be utilised at a localised level. It can use all types of waste which is advantageous, however, it is also seasonally based with usually only small amount of waste required (Archer et al., 2005).

A study conducted by Raa (1996) found that fish farmers were the first to consider the offal as a valuable resource and they contributed significantly to reducing local pollution and wastage by upgrading the waste to a valuable feed. At a local level fish offal can be simply mixed with straw, potato mash, or other carbohydrates to produce animal feed.

3.4 Ensiling

Ensiling involves fish waste, generally minced or chopped, put into a mixing tank and formic acid is added to acidify it. The inherent gut enzymes break the material down and the seafood waste is turned into a thick, viscous material which can be held in bulk storage. Ensiling is a permitted option for seafood waste, although it is currently considered an intermediate process before the ensiled material can be used for other purposes. Before the ensiled material can be used for other purposes, it must be heat treated. Ensiling is a process that is able to be used on a small scale level, in-house level or at a large scale since its establishment costs are low for the basic ensiling process (Archer et al., 2005). An example of costs experienced for a 2000 litre capacity tank for the basic ensiling process in England are shown in Table 3.

Table 3: Costs experienced from a 2000L ensiling tank

Capital cost	£8,000- £20,000
Storage tanks and ancillary equipment	£11,000
Operating cost (includes acid, labour etc)	£4,000- £7,000 p.a
Total costs (based on 8,000 capital costs) • If land injected • If exported • If collected free	 £55/t £89/t £31/t

There is potential for producing feed products from ensilage. Fish silage can be used in the extrusion process of animal (fish, pigs, chicks) feeds to improve the technological properties of the feed pellets and add an attractive taste to the feed (Raa 1996). Production of fish silage from a mixture of processing waste has become a significant industry in Norway, due to the demand for the partly digested protein of fish silage concentrates, which also contributes other valuable nutrients (Raa 1996). The nutritional value of fermented fish silage has been reported as good and biological value similar to skimmed milk powder or fish meal has been obtained (Ockerman and Hansen 2000).

Ensiling has also been used with crab waste and wheat straw. Addition of molasses to the crab waste and wheat straw mixture produced a feed with desirable fermentation characteristics and palatability (Abazinge, Fontenot, & Allen, 1994). Another study investigated the effects of fish silage inclusion into the feed of broiler chickens. The different techniques used included acidification with formic acid and fermentation with a starter culture with molasses (R. J. Johnson, Brown, Eason, & Summer, 1985). This study concluded that fish silage may be added to nutritionally balanced diets feeds for broiler chickens without affecting growth or taste, assuming appropriate precautions in the handling of fish before ensilage are followed (R. J. Johnson et al., 1985). A maximum of 100g/ kg of fish silage was added in this experiment. An additional study performed in Australia investigated fish silage prepared from Ocean perch and Nannygai and fed to grower pigs. Feeding fish silage resulted in an increased growth rate and decreased feed. It appears that an unidentified growth factor may be present in fish silage (Batterham & Gorman).

Ensiling is able to treat all forms of finfish waste, with low running costs. The technology used to treat waste is simple and there is a low environmental impact for the relatively quick treatment process. Some disadvantages include the material needing to be heat treated for further use. This can greatly increase the costs for this waste treatment option.

3.5 Alkaline hydrolysis

Alkaline hydrolysis is a waste treatment option whereby an alkaline solution of sodium hydroxide or potassium hydroxide or a combination of both are poured onto fish waste and used to aid digestion. Digestion time is set according to the type of waste added. The final product is a sterile alkaline material. Alkaline hydrolysis requires continuous operation for it to be cost effective. It is considered a medium to high cost option due to its expensive capital and running costs. Due to these high costs, small scale facilities are not considered to be feasible under this waste option. Although expensive alkaline hydrolysis produces sterile residues, it is a "clean" technology which has a relatively small footprint and has a quick treatment time (Archer et al., 2005).

3.6 Compost

Unprocessed fish waste decomposes rapidly which, along with the unpleasant odours makes it difficult to handle. The fish waste is usually stabilised for plant fertilisers via composting (Goldhor & Regenstein, 1991). Composting involves decomposition of the seafood waste to ensure that the microbial organisms have an optimum environment to thrive. Composting involves manipulating the natural decomposition. The decomposition organisms rely on an optimum ratio of carbon (C) to nitrogen (N). Seafood processing waste typically has a much lower C:N ratio and so a material high in carbon is added to ensure the balance is maintained (Martin, 2007). Aeration is also important in the composting process due to the microorganisms need for oxygen. Stable compost takes between 6-8 weeks to produce stable compost or possibly even up to 12 weeks if the product is to be bagged. There are a number of in-vessel technologies available, with trials being completed by Seafish and Bord lascaigh Mhara (Irish Sea Fisheries board) (Archer et al., 2005). There is currently a plant in Tasmania which is producing compost made from fish frames, milk factory by-products, abattoir manure waste, bio solids, municipal green waste and high quality wood chips (Management, 2012). Another company in Aberdeen, Scotland (Grays composting) have successfully used vertical composting units (VCU) to dispose of locally produced waste from shellfish (Morris). Mukhina (2003), describe a project where seafood waste is mixed with pulp and paper and wood working by products. The end product contained a full range of nutrients necessary for plant growth. A company in Singapore, Biomax has developed a rapid composting system that produces a shelf-stable product for potential use in feed in 24 hours.

Composting is able to process all types of seafood waste and the aerobic process reduces odours generated. There are also many other positives for composting including it reduces land emissions, volume reduction is achieved and it is economically viable in comparison to many other waste options. However, its process time is extended compared to other waste treatments, a large site is usually required for full scale production and transport costs are generally high due to low bulk density of the final product.

3.7 Fertilisers and soil conditioners

Fertilisers and soil conditioners are products which are currently being generated from seafood waste. A number of methods currently being employed include composting, rendering, drying at high temperatures and digestion (anaerobic or aerobic). These methods break the seafood down into its liquid and solid phases, which produce a nutrient fertiliser.

Some examples being trialled in Australia include the South East Fishery Industry Development Subprogram is an initiative of the FRDC setup to help find a solution to the large amounts of fish waste that are discarded by the Australian seafood industry each year (Knuckey et al., 2004a). The Australian Seafood Co-Products Pty Ltd (ASCo) was formed in 2001 with the objective of developing a disposal solution for waste generated from fish cleaning and filleting, approximately 60% of the original fish mass (Australian government, 2011). The solution, ASCo fertiliser, is a collaborative effort, made up of approximately 18 industry stakeholders including companies from the south eastern trawl and the FRDC. A joint venture relationship was established with a major Australian fertiliser company to help manufacture, brand, distribute and market the biological fertiliser. Engineering of the two stage manufacturing process to produce the biological fertilisers was constructed with funding assistance from the Geelong Innovation and Investment Fund. This company is a flagship for collaboration between Australian companies.

A fish waste rock phosphate fertiliser (BioPhos) which is currently being marketed in New Zealand to farmers, has had very promising results in increasing plant growth and yield production. A two year field trial which compared the fish based rock phosphate P fertiliser produced yields that were statistically equivalent to those achieved with super phosphate (Chitralekha, Rajan, & Mclay, 2000). Another company based in Boston is producing organic fertiliser using waste from farmed fish. The company are using a hydrolysis process by which skin and bones from filleted fish are removed, leaving the protein. The offal is then ground into a slurry form, processed and separated. The final product consists of 10% high quality fish oil and 4 % sediment, which is used for organic fertiliser, ground cover and hydrolysate ("A more profitable use for fish waste," 2011). Organic fertiliser appears to be a more profitable option than others such as fishmeal or oil. The organic fertiliser, similar to previous research, has shown that it has a slow release of fertiliser.

Fertiliser products appear to be the cost effective option currently due to the low volume and wide geographical area covered by Australia’s seafood industry (Knuckey et al., 2004a). Biological fertiliser is one of the strategies being introduced as a method of recycling seafood waste in a commercial setting which can generate regional economic benefits through innovation, collaboration and supply chain partnerships (Australian government, 2011).

3.8 Fish Glue

Fish glue production has considerably increased in recent years because of a demand for new types of adhesives (Ockerman and Hansen 2000). Fish glue is manufactured from fish skins and fish heads. The advantages of fish glue is that it needs no further preparation, it is ready for immediate application, and it can be used from the same container for several days. The slow setting time of fish glue allows the glue to penetrate the wood better and produces greater adhesion (Ockerman and Hansen 2000).

4. Tier 3 Complex value add

4.1 Fish bones

Fish bones are a by-product of flesh separation such as mincing or hydrolysis and are able to be used in filtration systems or in land remediation. Before use, the bones need to be subjected to a further treatment such as heat or enzymic to reduce organic content on the bones (Archer et al., 2005). To utilise fish bones, the facility would need to be developed in conjunction with a flesh recovery operation, such as mincing or hydrolysis. Fish bone meal is another option that could be marketed as a plant fertiliser. This product is already being marketed to organic and individual farmers in the US. It has been proven to contain high levels of phosphorus as well as significant secondary macro and micro nutrients necessary for plant growth (R. B. Johnson, Nicklason, & Barnett, 2003). Although this waste utilisation option is also only suitable for finfish waste it utilises a waste portion of seafood which has little other value. There is also a financial return on the finished product. Overall, it appears to be a suitable option if paired with a large scale finfish mincing or hydrolysis operation.

5.2 Fish hydrolysate

Fish hydrolysate is an inert liquid produced by enzymatic hydrolysis (Knuckey et al., 2004a). It occurs when an acid, commonly sulphuric acid, is added to ground whole fish or fish waste. The mixture is agitated to allow the endogenous enzymes in the fish to be released from the cells to digest the fish tissue (Knuckey et al., 2004a). Hydrolysis is an exothermic process and so insulation of the vessel allows heat to be retained and the process accelerated. Hydrolysis is usually completed within 48 hours when performed under ideal conditions. Once the process is finished the hydrolysed fish waste is passed through a screen to remove any solid material. Hydrolysing fish waste is effective with usually only 50kg of solid waste from 10 tonnes of fish by product (Knuckey et al., 2004a).

Hydrolysates can be of lower nutritional value in comparison to fish meal products however, due to its high digestibility it can be used in diet formulation for very young animals with immature digestive systems (Stone & Hardy, 1986). Hydrolysates therefore have potential to be included in aquaculture feed as sources of amino acids, feed binding agents and also for their palatability properties (lieske & Konrad, 1994). A South Australian company, SAMPI, successfully setup a pilot plant in 2004, to process the bluefin tuna and kingfish farm waste produced. It is now a fully functioning plant which processes in excess of 3000t of fish waste per year. The hydrolysate is currently sold Australia wide as a fertiliser (Sampi).

5.3 Drying seafood

Investigation into the production of dried seafood products from a variety of WA seafood products has been performed in a pilot study performed at Curtin University (Howieson, Tay, Iaschi, Hansal, & Newton, 2013). Fish frames and waste products were the experimental products used in the 50L dryer (Kingsun Bioscience Company Ltd). Dried seafood products are advantageous because of their extended shelf life of 1 year or more at ambient temperatures, under correct packaging/ storage conditions (Howieson et al., 2013). The pilot study performed by Curtin University investigated the economic feasibility for the production of dried seafood for the Asian market. To calculate the FOB Australia cost of production the following steps were followed:

- The raw material costs before drying were divided by the dry recovery rate. This results in a value for the raw material cost after drying
- Add plant and administration overhead cost for operating the drying process to the cost after drying
- Add assumed labour and material cost after drying
- Add plant and administration overhead cost for operating the drying process to the cost after drying
- Add an assumed profit margin of 25% to actually yield profit through producing the dried seafood product
- All values are summed up, resulting in the FOB Australia cost of production

The FOB calculation is then used as the basis to calculate the likely retail costs based in the need to add:

- Freight and insurance, including additional costs involved in getting the product to the customer, for example sea freight/ air freight charges to ahrf/ airport, sea/air documents fees
- Add importing costs including a 10% margin on the previous value and potential marine insurance premium costs
- Add potential import suties/ taxes for the Japan market
- Add wholesaling costs, including an assumed 30% margin, plus 20% retailing costs (expressed as a 20% margin).

Various samples were dried in the pilot study, these included, atlantic salmon, sardine frames, rosy threadfin bream, shark cartilage, octopus heads, barramundi frames, Australian salmon, escolar and salmon heads and skins. The present estimated costs of production for meal and oil from the dryer are $3600/ tonne. This cost is too high for viable commercial use of meal and oil in aquaculture feed (fish oil $1500/ tonne and fish meal $1200-1800/ tonne). Other uses for dried seafood products include (Howieson et al., 2013)

- High protein supplements for humanitarian situations
- Dashi: fish stock powder
- High omega and protein supplement for Korean poultry industry
- High protein supplements for premium pet food industry
- High value products from shark cartilage
- High protein supplements for survival foods
- Premium fish oil

Leather

Fish skins may be processed using the same methods terrestrial skins are processed to make leather. Common sources of fish leather include shark, salmon, ling, cod and hagfish skins.

Leather production is still considered a niche option and so if developed in conjunction with other waste utilisation options may be considered viable (Archer et al., 2005).

5. Tier 4: Premium value add: food, extraction for pharmaceutical additives, food additives, long life food

More recently by-products are being reassessed for human consumption and pharmaceutical/nutraceutical options. . Nutraceuticals are defined as "ingredients or extracts with clinically proven health promoting activity, including disease prevention and treatment" (Shahidi, 2003). Nutraceuticals are delivered as supplements or as functional food ingredients.

5.1 Mince

Fish flesh from the by-product stream is primarily recovered using mechanical techniques. Non mechanical methods are available, such as chemical separation, and produce higher yields than mechanical methods (Marsh & Bechtel, 2012). The mechanical separation methods are preferred because although chemical methods produce higher yields the quality of the mince is inferior (Archer et al., 2005). Whilst fish mince is a highly nutritious product the disadvantages lay within its aesthetic appeal. The highest grade of mince is used for human consumption for various food products. Lower grade mince are commonly used in pet food (Archer et al., 2005). Mince colour is a major factor, from white fish, in consumer acceptance. The darkening of the mince as well as the lack of colour homogeneity are disadvantages. Strategies for improving the colour include whitening using hydrogen peroxide or titanium dioxide. Masking the colour by the addition of other ingredients such as curry flavouring are also a viable option (Taylor, Himonides, & Alasalvar, 2007). Small scale mince production can be inexpensive, with basic deboning equipment running at a capacity of 0.5t/ hr costing around £15,000 (Archer et al., 2005). Cost of freezing equipment is dependent on capacity. Other factors which must be considered for this waste option include labour packaging and transport costs. The type and scale of mince production is flexible and it utilises a good range of raw materials. A wide range of food products are also able to be produced from mince. Hence there is great opportunity for the development of new markets. Some disadvantages include larger scale operators facing higher capital and operational costs. Also the legislative requirements for hygiene and operation are set very high. China appears to have dominated the market in production of commercial blocks (Archer et al., 2005).

5.2 Roe

Fish roe is derived from the eggs carried by female fish during the breeding season (Archer et al., 2005). Most roe products are derived from cod, herring, capelin, lumpfish and salmon (Archer et al., 2005). Roe may be extracted mechanically, which results in separate non sticky eggs, or manually, which is considered more of a delicacy. Roe is a highly valued product and so it almost always recovered and marketed (Bledsoe, Bledsoe, & Rasco, 2003). Its value was demonstrated in 2003 when (Arason, 2002) reported that although roe only represented 6% of the quantity of groundfish by products exported from Iceland in 2001, it contributed 26% to the total value. The Japanese market for roe is estimated to be worth £500 million per annum, with imports worth a total of £367 million. Currently only roe from pelagic species are harvested. Extracting roe from demersal fish would maximise an underutilised resource. Hence, there is opportunity to develop new niche markets within the already existing market. Roe recovery is a potentially lucrative utilisation route, however, the primary and secondary processing would need to be assessed individually using a detailed cost benefit analysis (Archer et al., 2005).

5.3 Fish heads

The texture and flavour of meat retrieved from fish heads are considered a delicacy. There is a demand for fish tongues and cheeks in many countries so marketing opportunities exist. Tongue and cheek flesh is able to be used in the production of fish mince, pies, fish cakes and reformed products (Archer et al., 2005). In certain parts of Europe the tongue and cheeks are retailed at similar prices to the fillets. In Nigeria, salted and fermented cod heads are considered a delicacy, whilst in Iceland popular dishes include dried fish heads (Archer et al., 2005). The costs of removing tongue and cheek flesh has low capital costs, although it is labour intensive (Archer et al., 2005). The introduction of mechanical automation of the process for removing the tongues and cheeks greatly reduces labour requirements and costs (Arason, 2002). Drying fish heads can be a costly operation due to high energy costs. Although Iceland has demonstrated these costs may be reduced using a heat efficient pump (Archer et al., 2005). Utilising this fish waste has a high potential value; it offers an increased income for the catching sector and can be performed by most processors. Many countries have also established markets for this type of product. Some disadvantages of utilising fish heads include fish that are too small to be utilised, the cost of freezing and transport to European markets and this method is only viable for fish, not crustaceans (Archer et al., 2005).

5.4 Soups, stocks and sauces

Soups, stocks and sauces can be produced from fish and shellfish waste (as reviewed by Lopetcharat et al., 2001). The costs of setting up a production facility are unknown, however, it would depend on the extent of the facility and the complexity of the process. Preparation of stocks, soups and sauces utilises many different types of fish and shellfish. This sort of waste management could easily be added to an existing processing plant and has the potential for a successful export market. Ideally, this method of waste utilisation should focus on identifying new markets and sourcing material which is underutilised to be a successful option (Archer et al., 2005). A study performed in Australia, investigating the feasibility of producing acceptable prawn stock from the discarded heads of commercially processed prawns was performed in 2001 (Hancock, 2001). A prototype prawn stock powder was produced (Table 4) from the project however, the project was terminated before any feedback from Japanese markets was collated.

Table 4: Ingredients for a prototype prawn stock powder

Ingredients	%
Carrot Slice (fresh)	2.9%
Celery Slice (fresh)	1.4%
Tomato Puree (canned)	4.6%
Salt	0.8%

Whole Black Peppercorns	0.06%g
Prawn Heads	22.9%g
Onion Slice (fresh)	5.7%
Bay Leaves	0.04%
White Wine	2.3%
Lemon Juice	2.3%
Water	57.0%

Fish protein concentrate

Fish protein concentrate (FPC) is a highly nutritious powdered product made from whole fish. FPC contains a protein concentrate higher than that of the original fish. FPC, depending on its degree of refinement may be used as a food ingredient to boost protein content or in some less developed countries eaten directly as a food product. FPC is normally made from whole fish and so although an option is not a likely waste utilisation method (Archer et al., 2005).

Fish protein hydrolysate

Fish protein hydrolysate (FPH) is a powdered product, produced by the use of enzymes to break down fish proteins into amino acids. The resultant product is capable of whipping, gelling and texturing properties when used as an ingredient in food products. Although quite versatile its bitter flavour and fishy odours leave it as an unsuitable option for waste utilisation (Archer et al., 2005). FPH is now commonly produced using commercial enzymes as they are able to improve the nutritional value and functional properties of FPH. FPH peptides are also antioxidants which have antihypertensive, anticancer and antianemia properties. So FPH may have other uses than just within the food industry (Herpandi, Rosma, & W.A., 2011).

Pharmaceutical nutraceuticals and other products

Omega-3 fatty acids

The most successful bioactives extracted from marine sources are probably th long chain omega 3 fatty acids. These are extracted from fish oil (for more details see Olsen et al., 2014).

Collagen and Gelatine

Other examples include collagen and elastin extracted from fish skin (Nagai & Suzuki, 2000). Collagen extracted from fish skin and bone have applications within the cosmetic, medical and pharmaceutical industries (Losso, 2007)

Collagen is a common protein found in skin and bones and specifically isolated from the skin, bones and fins of fish. These waste items are dissolved in heated dilute acid or salt solution to extract the collagen. Fish gelatine is a sweet solution with the capability to form gels. Fish gelatine has many uses, including photographic processing, coating applications and in food products. The material used for collagen production usually consists of material typically left over from other utilisation options. Some disadvantages of the method include skin and bones must be as free from protein as possible and a large volume is required. This waste utilisation option appears to be a viable as there appear to be opportunities to work with existing gelatine producers to establish fish based production (Archer et al., 2005).

There have already been studies performed on numerous fish species which have shown to have good gelling properties, these include bigeye snapper (*Priacanthus hamrur*) (Binsi, Shamasundar, Dileep, Badii, & Howell, 2009), cuttlefish (*Sepia pharaonis*) (Aewsiri, Benjakul, & Visessanguan, 2009), greater lizardfish (*Saurida tumbil*) (Taheri, Abedian Kenari, Gildberg, & Behnam, 2009), grouper (*Serranidae* sp) (Rahman & Al-Mahrouqi, 2009), Hoki (*Macruronus novaezelandiae*) (Mohtar, Perera, & Quek, 2010) and giant catfish (*Pangasianodon gigas*) (Jongjareonrak et al., 2010).

Fish collagen has also been studied in numerous fish species. These include trout and hake (Montero & Borderías, 1991), plaice (Pleuronectes platessa) (Montero, Álvarez, Martí, & Borderías, 1995), squid (Illex coindetii) (Ruiz-Capillas, Moral, Morales, & Montero, 2002), deep-sea redfish (Wang, Yang, & Regenstein, 2008), threadfin bream (Nalinanon, Benjakul, Visessanguan, & Kishimura, 2008)), walleye pollack (Yan et al., 2008), brownstripe red snapper (Jongjareonrak, Benjakul, Visessanguan, Nagai, & Tanaka, 2005) or unicorn leatherjacket (Aluterus monoceros) (Ahmad, Benjakul, & Nalinanon, 2010).

Enzymes

Enzymes are biological catalysts, used to speed up favourable chemical reactions. Some protease enzymes including pepsin, trypsin, chymotrypsin, collagenases and calpains are able to be extracted from the gut and viscera of demersal and pelagic fish, cephalopods and shellfish. These enzymes have many commercial applications because they possess a unique ability to work at low temperatures within a neutral to alkaline pH. Enzyme extraction involves mincing the fish, followed by repeated centrifugation and precipitation to remove solid material and concentrate the enzyme. The final stage of purification involves using ultra filtration followed by drying to stabilise the enzymes. Enzymes are a valuable product, for which the demand is expected to increase. Establishment of a plant that could carry out enzyme extraction would incur substantial costs and there would need to be a method of obtaining viscera and stomachs quickly so as to maximise enzyme quality. Ideally, there is opportunity for the seafood industry to supply waste to a biotechnology company to produce the enzymes (Archer et al., 2005). However, the improvements in fish technology, for example pre-treatments and characterisation still need to be improved before this can be a viable option (Rebah & Miled, 2013).

DNA

A range of high value chemicals have been produced from fish and shellfish. Some examples include the DNA of cod, herring and salmon milt harvested in Norway being extracted for pharmaceutical use. The DNA has many uses including that it may be further processed into the drug AZT which has been used in the treatment of HIV (Archer et al., 2005) .

Squalene

Another is squalene, a naturally occurring hydrocarbon found in plant and fish oils, which is extracted from shark livers. Squalene has been used to treat diabetes, cancer and tuberculosis. To look at producing pharmaceuticals, cosmetics and chemicals from seafood waste, the most effective option would be for the seafood industry to work with the pharmaceutical companies to supply raw materials (Archer et al., 2005).

Chitin and chitosan

Chitin is a major component of the exoskeleton of crustaceans which can be extracted and applied in many broad areas. Chitin is extracted by finely grinding the shell of the crustacean and washing it with dilute acid and alkali to remove unwanted proteins and minerals (Archer et al., 2005). Chitin is very versatile, as a membrane it may be used from water filters to high definition speakers. When chitin is further processed it becomes chitosan, which has antibacterial and anti-clotting properties. If chitin is further reduced to its basic building block, glucosamine, it may be used to relieve arthritic pain. An example of how seafood processing waste may be utilised was trialled in a 2006 FRDC project. Examination of the Western Australian rock lobster industry discovered that the discarded lobster heads which were incurring a disposal fee were a potentially high resource of chitin (Makha, 2006). The project investigated a green sustainable process technology which extracted chitin and associated derivatives from rocklobster waste (Makha, 2006). This production method is unlike those existing overseas. It uses a simple process based on recyclable biomass-derived solvent and conversions avoid the use of highly concentrated caustic solutions (Makha, 2006). Establishing chitin as a waste option would require significant investment. Although there is a great demand for the valuable product its extraction process is expensive and the method itself produces waste which would need to be disposed of. Quality is also difficult to control (Archer et al., 2005).

Astaxanthin

The carotenoid, astaxanthin is added to aquaculture salmon feed to produce the pink flesh coloration, and it is estimated that >95% of the product is product is produced synthetically for cost reasons. However there has been ongoing research into biological source of the pigment and the extraction of astaxanthin from crustacean waste has been reported. However the concentration is low even when compared to other microbial sources such as *Haematococcus pluvialis* so establishment of an economically feasible process is at this stage considered unlikely (Olsen et al., 2014)

6. Final Conclusions

A recent review analysed the mot feasible opportunities for conversion of seafood processing waste into commercial products (Olsen et al., 2014). The review found that the most realistic uses of by-products from fish processing are as food or indirectly as food by producing feed ingredients. However, this upgrading for potential human consumption requires that quality assurance systems (such as HACCP) are implemented and this may not always be possible without significant capital expenditure.

The review further found that the rising prices of fish oil and fish meal for aquaculture use mean that these should not now be considered as low value products. In addition advances in smaller volume/mobile systems have expanded the ability of smaller seafood processors to produce such products.

With the exception of long chain omega 3 fatty acids from certain materials, extraction of high-value bioactive compounds was reported to be unrealistic in most cases. Reasons include lack of existing markets, high costs of extraction, too small amounts of high quality source material, and cost of developing appropriate support documentation. In addition (as with the extraction of astaxanthin from crustacean shell), usually the cost of chemical synthesis is cheaper than the extraction process, or the compound can be produced by GM organisms.

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