New Opportunities for Seafood Processing Waste

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September 2017

FRDC Project No 2013-711.40


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ISBN 978-0-9925568-5-3

Final Report: Options for Utilisation of Seafood Processing Waste
FRDC 2013/711.40

2019

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

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Executive Summary

This report summarises the research undertaken under FRDC 2013/711.40: New Opportunities for Seafood Processing Waste.

The project commenced with a literature review and then an audit of the seafood processing waste estimated to have been produced in 2013 in Australia. Likely to be the most accurate assessment undertaken thus far in this field, the audit estimated different forms and feasibility of access for the waste in Australia. The resulting volumes (whilst now historic but upgradeable), with limitations, now allow a more informed evaluation of potential economic opportunities from seafood processing waste.

The audit formula used the production volumes of major seafood lines fished/produced in Australia, then after subtracting export and domestic consumption figures for whole/live product resulted in a volume of product that was likely to be destined for seafood processing. This volume was then adjusted based on a calculation for each seafood line of the inedible/edible percentages remaining following processing. For the purposes of the audit the processing waste categories were separated by processing location (on board or land-based) and separated into white fish, red fish (predominantly farmed Atlantic Salmon), shark, sardines, tuna (ranched and wild harvest), prawns (farmed and wild harvest), rock lobster, Blue Mussels, oysters, abalone (wild and farmed), scallops, cephalopods, other molluscs and other crustaceans. White fish were listed as one category as it was considered that a processing facility would not be able to economically undertake further separation of the white fish category.

The total amount of waste produced in Australia based on 2013 figures, was considered to be around 59000 tonnes. Based on all the fish production data (shark, sardines, tuna, white fish, red fish) not including off shore or at sea processing, and assuming, based in industry advice, that 50% of white fish and 70% of red fish is processed at establishments large enough to undertake serious activity, it was estimated that around 31131 tonnes of fish waste is available for significant waste transformation activity. Waste from the mollusc categories (oyster, Blue Mussels and scallops) is primarily due to product not being to specification and shells. It was estimated that around 422 tonnes each of shell and meat/shuckings was available.

At the time of the audit industry partners were also asked their current status of processing waste management and their ideas or the future. This Industry comment from the survey was also an important outcome, demonstrating that many companies are committed to investigating new methods to treat their processing waste.

Industry consultation and the development of a modified value chain analysis framework for new products from processing waste resulted in eleven industry case studies being identified for the project: these included products for potential waste transformation such as on board Patagonian Toothfish waste, land-based tuna and other finfish waste, abalone shuckings, pearl oyster adductor muscle, scampi roe, octopus heads and offal, swim bladders of various species and out of specification Blue Mussels. A variety of different waste transformation techniques were trialled including enzyme and acid hydrolysis of frames, offal and bones, curing of roe, drying and milling, enzyme extraction, oil extraction, composting and flavoured stock production. As a result a variety of products for different outcomes were produced, and compositional and shelf-life analyses completed on each of them.

For each processing waste case study, an individual report summarising the methods and results was produced and provided to the industry partners as well as generally being made available as publishable appendices to this report. Some of the outcomes were for non-human products such as Patagonian Toothfish, tuna and other finfish hydrolsate for fertiliser, aquaculture feed or pet food, composting products, low quality oil and extracted enzymes for potential addition to detergents. However there were also some high value food products produced including scampi roe, Blue Mussel stock, pearl meat adductor muscle and fish maw (swim bladders). In total, of the eleven industry requested case studies commenced, three new products have been commercialised (tuna hydrolysate, scampi roe and pearl adductor muscle), and a number of other products are in market/commercial trials.

A generic cost benefit template for the project was produced and specific cost benefit analyses undertaken on two of the products (pearl meat adductor muscle and tuna hydrolysate). Positive cost benefit analyses long term were identified for these two commercialised products. The cost benefit template developed can now be easily used in assessments for other products (eg the Blue Mussel stock, dried air bladders and the scampi roe) but at this stage industry partners thought it was premature to provide the data necessary for the detailed cost benefit analysis. However preliminary costings on the Blue Mussel stock, the Patagonian Toothfish on board processing and the scampi roe production were provided to the companies as part of the company specific reporting.

The results of the project have been extended in a variety of both industry specific and academic written and oral formats. A generic framework for approaching similar research in the future has been formulated, new seafood waste treatment methodologies have been developed and proof of concept shown for several commercial case studies. A number of post-graduate students have been trained in seafood waste transformation. Several new waste research and policy initiatives are in development based on the project findings.

In conclusion it was clearly evident that the Australian seafood industry generally is looking at new ways to utilise processing waste, as shown in the industry interest and commitment to the various case studies undertaken as part of the project.

1. Introduction

In 2006, it was estimated Australia produced 100,000 tonnes of seafood waste at an estimated cost of disposal of AUD$15 million (Peters & Clive (2006). An overview of the Australian seafood industry). Currently much of this waste is processed as pet food and fish oil or dumped into landfill (Waste Classification in Australia, Hyder Consulting 2011). As a result developing new opportunities for seafood processing waste was identified as a priority research area for CRC 2013/711, CESSH Sub program 2 (Seafood Post Harvest Improvement) and later as part of FRDC 2013/711.40: New Opportunities for Seafood Processing Waste. This report summarises the results of both projects.

Better management of processing waste in the seafood industry could lead to greater market opportunities, improved returns and reduced costs for seafood operators. An estimated 10,000 tonnes of Australian seafood processing waste is currently put in landfills because it is produced in disparate locations and in volumes too low for cost-effective processing on site. However as the cost of waste disposal and the potential value of by-products increase, and consumers pay more attention to total product utilisation and food security, reducing and transforming seafood processing waste has been identified as a new opportunity to add profitability to the Australian seafood industry.

2. Objectives

1 Develop at least three new value add opportunities from seafood processing waste.

2 Develop a framework for identifying and capitalising on opportunities for value adding of seafood processing waste

3. Methods

3.1 Literature Review and Development of Tiered Framework for Seafood Waste Utilisation

At the commencement of the project a literature review was completed and, based on the literature review, a seafood processing waste tiered framework approach developed to assist in targeting objectives for specific seafood processing waste sources.

In addition the project investigators modified existing seafood value chain analysis (Howieson et al (2016) and new product development (Howieson et al., (2013) frameworks to develop an approach to identifying and implementing research to develop new product opportunities from seafood processing waste.

3.2 Audit of Seafood Waste in Australia

A formula to estimate the volume of waste produced from seafood processing operations in Australia was established after gaining feedback from speaking with industry processors and from industry reports. The formula used the production volumes of major seafood lines produced in Australia, then after subtracting export and domestic consumption figures for whole/live product, resulted in a volume of product that was likely to be destined for seafood processing. Production and export volume figures were sourced from the Australian Government Department of Agriculture publication “Australian fisheries and aquaculture statistics 2013" published in November 2014. The statistics used for the purpose of these estimations included production figures from 2012/2013.

To complete the formula, data from a literature review undertaken by a CESSH student project (Hee An Anna Seah (2014) (reproduced in Figures 1 and 2) and also from a finfish waste utilisation study undertaken by another student Jenny Ng (Ng 2010) (reproduced in Table 1) was then used to estimate the percentage of waste (inedible) portion of each seafood product line during the processing phase.

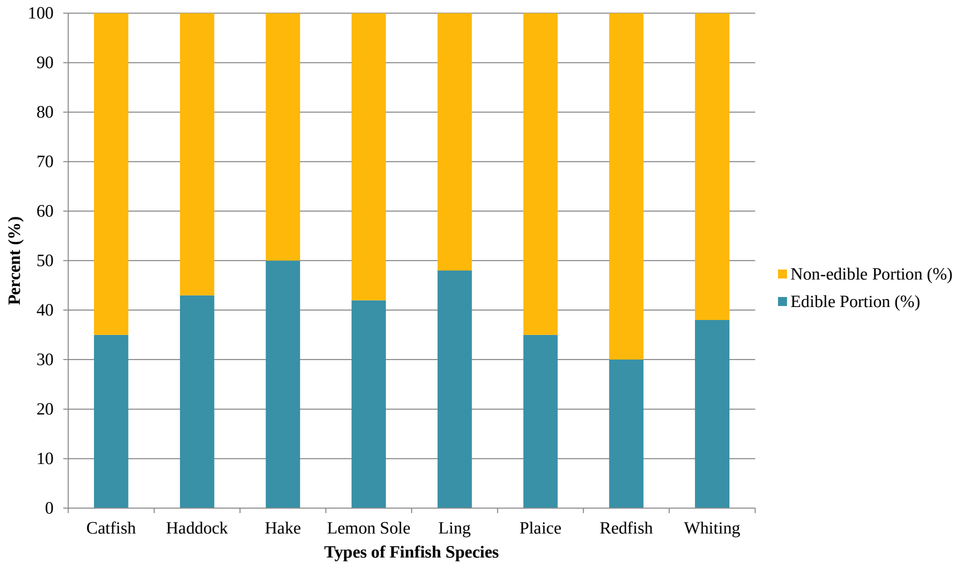

Figure 1: Edible and non-edible protions of finish species

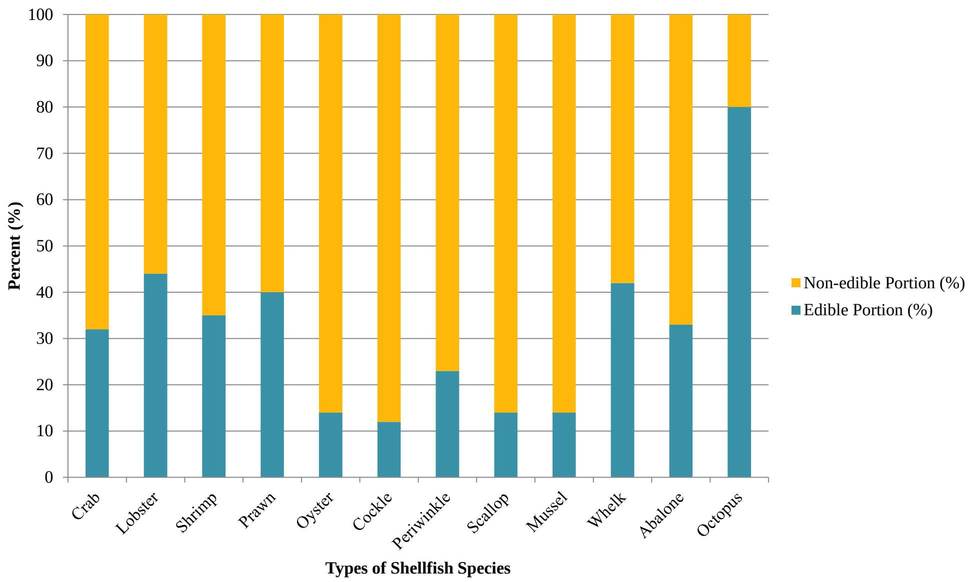

Figure 2: Edible and non-edible protions of other seafood species

Table 1: Waste produced from four commercially caught Australian finfish species (Ng 2010)

	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%

Net volumes of seafood product lines (after whole/live export and domestic volumes were taken out) were multiplied by the non-edible percentage for the specific product type to give a total processing waste estimation for each seafood product. For finfish, based on industry consultation, it was considered that 50% of processed white fish and 70% of processed red fish were being processed at a facility large enough to consider economic viability in waste transformation. Hence these figures were used for the calculation.

For the purposes of the survey the processing waste categories were separated by processing location (on board or land-based) and separated into white fish, red fish (predominantly aquacultured Atlantic Salmon), shark, Australian Sardines, various tuna species (aquacultured and wild harvest), various prawns species (aquacultured and wild harvest), rock lobster species, Blue Mussels, oysters species , abalone species (wild harvest and aquacultured), scallops, cephalopods, other molluscs, other crustaceans. White fish were listed as one category as it was considered that a multi-species processing facility would not be able to economically undertake further separation of the white fish category.

Data obtained from resources such as the Australian fisheries and aquaculture statistics were validated against other secondary sources including industry website information, literature reviews and industry publications. The information was also compared to that obtained via speaking directly with industry and checking all data was consistent.

Comments from industry partners about the waste issue, their current status and possible opportunities were also recorded as part of the audit activity.

3.3 Industry Consultation, Identification of Potential Opportunities and Committed Industry Partners.

To develop strategic direction for the project a priority setting workshop was held in November 2013 with invitations sent to 24 leading WA seafood companies.

This workshop, which was facilitated by Professor Fran Ackermann, Director of Research, Curtin Business School, used an innovative consultative process, “group explorer” which enabled all who participated to contribute their views via networked laptops. All participants issues and opportunities were then anonymously displayed on a main screen allowing them to be viewed, developed, and finalized. The workshop also included an anonymous opportunity to indicate no, “in kind” or “cash” support of the priority projects identified, this allowed further prioritisation of the activities .identified by the workshop participants.

The attendees were

John Sharland (Endeavour Foods), David Carter (Austral Fisheries), Steven Hood (MG Kailis), Simon Little (Westmore Seafoods), Peter Jecks (Abacus Fisheries), Charles Francina and Daniel McCorey (Fish Trade), Drew Martin (Sealanes), Toby Abbott (Kailis Bros) and Paul Catalano (Catalanos Seafoods). Apologies and request for updates were received from Richard Buczak (Central Seafoods), Arno Verboon (Fremantle Octopus) and David Thompson (Indian Ocean Lobster)

Figure 3: Group Explorer session to identify priorities

The results of this consultation was used to select initial case studies for the project.

As the project progressed with further industry consultation and extension mechanisms engaged, and following individual industry requests, further case studies were added if the intended activity fitted the modified value chain/new product development framework described in the result section.

3.4 Laboratory/Pilot Scale Trials

If an identified industry supported waste transformation opportunity was selected for further study, a series of generic protocols were instigated, with specific experimental protocols attributed to specific products. These generic protocols are described below. For the majority of case studies, a detailed experimental report was prepared for the industry partner, these individual product reports, including the product specific methodology are presented as appendices to this report as described below.

Appendix 2 SAMPI Tuna Hydrolysate Production

Appendix 3 SAMPI Tuna Hydrolysis Process: Options for Tuna Bones

Appendix 4 Investigation of On Board Strategies To Transform Patagonian Toothfish (*Dissostchus eleginoides)* Waste

Appendix 5 Patagonian Toothfish digestive enzyme purification and activity characterisation

Appendix 6 Strategies for Potential Utilisation of Aquacultured Abalone Waste

Appendix 7 Investigation of Biomax Process For Hydrolysing Seafood Waste

Appendix 8 Kinkawooka Blue Blue Mussel Stock: Optimisation of Blue Mussel Stock Production Using 2nd Grade Blue Blue Mussels

Appendix 9 Scampi Roe Product Development

Appendix 10 Paspaley Pearl Meat: Fresh v Frozen Pearl Meat Quality

Appendix 11 Paspaley Pearl Meat: Frozen Pearl Meat Shelf Life Determination

Appendix 12 Barramundi Swim Bladders: Optimisation of Sanitising, Cleaning And Drying Of Air Bladders For Human Consumption

Appendix 13 Small Scale Dehydration of Air Bladders from Different Species Of Fish To Produce Fish Maw

The generic methods are described below:

3.4.1 Sample Sourcing, Handling, Storage

Generally, waste products were sourced by the relevant industry partner from their commercial operations, packaged, frozen and then transported to Curtin University. Samples were generally stored, labelled in a chest freezer. Thawing was generally completed overnight at 4˚C. Sometimes, at later stages, samples were transported, chilled in eskies with ice packs, then stored at 4˚C in a refrigerator until experimentation.

3.4.2 Waste Transformation Processes for New Product Development

A number of different waste transformation processes were developed in the project. These various processes are described below.

Hydrolysis (acid and enzyme)

Hydrolysis is a process which results in the breakdown of larger protein molecules into smaller peptides and amino acids. It can be completed by acid, alkaline (not completed in this project) or enzyme addition.

Small scale hydrolysing experiments were carried out in a Sunbeam Sous Vide/ Slow Cooker (see Figure 4). Generally ~2kg of waste product was hydrolysed at a temperature of 55˚C for two or more hours. Depending on experimental protocols, water was added at various rates. Hydrolysis was achieved either by acid (phosphoric or formic) or commercial enzyme (eg alcalase, protamex or flavourzyme) addition.

Figure 4: Patagonian Toothfish head and offal hydrolysis (before and after) in Sunbeam sous vide cooker

For larger scale hydrolysis experiments a 40L custom made unit was designed in consultation with industry partners and constructed (Figure 5). The unit included automatic stirring and heating, an in built sieve to hold the bones, a tap for the liquid to be emptied and was designed to be easy to clean.

Figure 5 40L experimental hydrolysis unit

Experimental hydrolysis was ceased either by pH adjustment or by heating to 95˚C to denature the enzymes. Following hydrolysis the bones were sieved and weighed (see Figure 6). Liquid was generally centrifuged and separated into the different hydrolysis components for compositional and other analyses (see Figure 7).

Figure 6 Separation of bones following hydrolysis

Figure 7 Centrifuged hydrolysate

Freezing

According to the experimental protocols, samples were occasionally frozen, either in a domestic chest freezer, or a commercial blast freezer.

Curing

When curing was required salt (between 0.5 and 2.5% depending on experimental conditions) was mixed in gently before placing the samples in metal sieves and curing for 1 hour at 4°C

Drying

Drying trials were generally completed in ovens set at the relevant temperature. Samples were laid on baking paper. Dried samples were sometimes milled/ground.

Grinding/Milling

Various manual or automated grinding/milling procedures were undertaken depending on the characteristics of the product to be milled. Further details are available in the aligned appendix.

Enzyme Extraction

The enzyme extraction method was adapted from several sources in an attempt to extract the majority of digestive enzymes (Ketnawa, Benjakul, Martínez-Alvarez, & Rawdkuen, 2017; Pavlisko, Rial, De Vecchi, & Coppes, 1997; Zhou, Fu, Zhang, Su, & Cao, 2007). The method is described below:

1. Prepare 200 mM sodium phosphate buffer, 4 mM EDTA (pH 7.5 at 4°C) (4x concentrate)
2. Gently remove the stomachs from the other organs
3. Homogenise stomachs with two volumes of 50 mM sodium phosphate buffer, 1 mM EDTA (pH 7.5) for 1 min in a blender
4. Centrifuge 4 000 *g* for 20 min, 4°C, discard pellet
5. Add ammonium sulphate to final concentration of 30%
6. Centrifuge 4 000 *g* for 20 min, 4°C, discard pellet
7. Add ammonium sulphate to final concentration of 70%
8. Centrifuge 15 000 *g* for 20 min, 4°C, discard supernatant, retain pellet
9. Freeze pellet at -80˚C prior to freeze drying a. Freeze dry conditions: -30˚C, 0.37 mBar

3.4.3 Analysis

Compositional Analyses

Moisture Content

The Association of Official Analytical Chemists (AOAC) official method 950.46 (AOAC, 2008) in meat moisture content was used to analyse the moisture content of a sample. Approximately 10g of each sample was weighed accurately into previously dried and tared aluminium dishes and dried in the 105^{0}C air oven (Contherm, digital series, oven, Lower Hutt, New Zealand) until constant weight. Before reweighing and moisture content measured by difference, the samples were cooled in a desiccator. The moisture content was determined by weight difference between before and after the drying process.

Ash

The ash content determination was conducted based on the AOAC official method 938.08 (AOAC, 2005). Approximately 5g was accurately weighed into pre-dried and cooled crucibles. Samples were ashed at 550^{0}C in a Thermolyne muffle furnace model 48000 Furnace (Thermo Fisher Scientific Inc, Iowa, USA) until constant weight (around 18 hours). Percentage of ash was calculated by the following equation:

$$\% \text{ Ash} = \frac{(\text{ashed weight} - \text{crucible weight})}{(\text{pre-ashed weight} - \text{crucible weight})} \times 100\ \%$$

Protein

Protein content was measured by using the Kjeldahl method according to the AOAC Official Method 955.04 (AOAC 2005). Approximately 1g of each ground sample was weighed and then put it into digestion tubes containing 1 Kjeldahl catalyst tablet (contains 1g Na_2SO_4 and 0.01g Selenium) and 2 or 3 glass beads to which the 8ml digestion acid (100 parts conc H_2SO_4 and 5 parts conc H_3PO_4) and 4ml of 35% hydrogen peroxide was added. The sample was then digested in a Tecator 2020 Digester (Höganäs, Sweden) at 420^{0}C until a clear straw colour was reached. Into the digest 50ml of 40% sodium hydroxide was added and steam distilled in a Kjeltec system 1002 distilling unit, (Foss Tecator, Höganäs, Sweden). The distillate was captured into a flask containing 25ml of boric acid as an indicator (80g of boric acid, 20ml of bromocresol green solution and 14ml of methyl red solution and diluted to 2L with deionised water). The distillate was titration against 0.1 M Hydrochloric acid. One gram of sucrose was used as a blank. The percentage of protein in the samples was calculated using the following equation:

$$\% \text{ Protein} = \frac{(\text{sample titre mL} - \text{blank titre mL})}{(\text{mg sample})} \times 0.1 \text{ M HCL} \times 14.1 \times f \times 100\ \%$$

The conversion factor (f) was 6.25, which is the general factor used for meat and fish products.
When specific amino acid species composition was required, samples were despatched to commercial laboratories (usually National Measurement Institute (NMI)) for amino acid breakdown.

Fat

The method for crude fat determination followed the AOAC official method 960.39 for meat (AOAC 2005). Approximately 1.5 g dried sample was ground, weighed and put into a thimble recorded as weight 1. An extraction cup, which is a specific glass beaker in which the fat will collect containing a glass bead, was weighed and recorded as weight 2. The fat was extracted in a Soxhlet Buchi fat extraction unit (Model E-816, Buchi Labortechnik AG, Flawil, Switzerland) over ten cycles or a one-hour period, with petroleum ether (boiling point range 40^{0}C–60^{0}C) as the extraction solvent. After extraction, the extraction cup was dried in the 105^{0}C air oven (Contherm, digital series, oven, Lower Hutt, New Zealand) until it reached a constant weight, and was then cooled in a desiccator. Crude fat was calculated as per the equation below:

$$\% \text{ Crude fat} = \frac{(\text{Wt of extraction cup containing fat - Wt of empty cup})}{(\text{Wt of thimble and sample} - \text{Wt of thimble})} \times 100\ \%$$

When specific components of the fat were required, samples were provided to National Measurement Institute (NMI) MI for Fatty acid methyl ester (FAME) analysis.

Oil quality as peroxide levels or free fatty acid measurements were conducted as required by NMI.

Heavy Metals

If heavy metal analyses were required, samples were outsourced, usually to NMI.

Microbiological Analyses

Where microbiological testing was relevant, duplicate samples were sent for analyses at a NATA accredited laboratory. Generally the samples were analysed for Total Plate Count (TPC) and for *E.coli* and *Listeria monocytogenes* with samples assessed to comply with the Food Standards Code.

Shelf-life testing, if required, was generally outsourced to a NATA accredited laboratory.

Sensory Analyses

If the new products were intended for human consumption sensory analysis with trained or untrained panelists were carried out. Ethics approval was obtained from the Curtin Human Research Ethics Committee (HREC) and information and consent forms were provided to participants. Specific details of the sensory analyses are in the aligned appendices but generally samples were assessed using acceptability rating scales for appearance, odour, texture, flavour and overall acceptability.

Other Analyses

Proteinase Activity

The colourimetric proteinase assay utilising Folin's reagent is a commonly used method for quantitatively determining proteinase activity. The method described by Cupp-Enyard (2008) from Sigma-Aldrich was used with some modification. This method has been used successfully in a previous project and successfully adapted for microplate use. One unit of protease activity was defined as the production of 1 µmole of product per minute per millilitre at pH 7.5 and the stated temperature.

1. Prepare a 50 mM sodium phosphate buffer, pH 7.5 at 37˚C
2. Prepare a 0.65% casein solution using the previously prepared phosphate buffer. Heat solution to 85˚C with stirring to solubilise the casein
3. Prepare a 110 mM trichloroacetic acid solution
4. Prepare a 0.5 M Folin & Ciocalteus Phenol reagent on the day of use
5. Prepare a 500 mM sodium carbonate solution
6. Prepare a 10 mM sodium acetate buffer with 5 mM calcium (calcium acetate), pH 7.5 at 37˚C
7. Prepare 1.1 mM L-tyrosine standard stock solution. Gently heat and stir solution to solubilise L-tyrosine
8. Using 1.5 mL Eppendorf tubes, add 500 µL of casein solution and equilibrate to 37˚C in water bath
9. Carefully managing time (30 seconds between each test sample) add 100 µL of enzyme sample dissolved in acetate buffer to the casein solution, vortex, and allow to sit in water bath at 37˚C for exactly 10 minutes a. For blanks add 100 µL of acetate buffer instead of enzyme sample

10. At 10 minutes add 500 µL of TCA and vortex to stop the reaction
11. Incubate samples for 30 minutes at 37˚C
12. Prepare L-tyrosine standards

13. Centrifuge samples at 2000 *g* for 5 minutes at 37˚C
14. Draw 250 µL of cleared solution and dispense into new Eppendorf tubes
15. Add 625 µL of sodium carbonate solution immediately followed by 125 µL of Folin's reagent to all standards, samples and blanks, vortex
16. Incubate at 37˚C for 30 minutes

17. Centrifuge samples at 2000 *g* for 5 minutes at 37˚C
18. Pipette 200 µL of sample into microplate and read absorbance at 660 nm

Lipase activity assay using DTNB

A rapid colorimetric microplate lipase assay was used with some modification (Choi, Hwang, & Kim, 2003). The thioester substrate (2,3-dimercapto-1-propanol tributyrate (DMPTB)) releases free thiol groups when hydrolysed by lipases; these products then reduce 5,5'-Dithiobis(2-nitrobenzoic acid) (DTNB) releasing the chromophoric 2-nitro-5-thiobenzoate anion, which can then be measured at the wavelength 405 nm. Specific activity represents the production of 1 µmole of product per minute per milligram of protein; this definition was also used for the protease assay.

1. Prepare 0.5M Tris-Cl buffer (pH 7.5 at 37˚C)
2. Prepare 40 mM DTNB in 100% methanol
3. Prepare 50 mM Tris-Cl buffer (pH 7.2 at 20˚C), 6% TritonX-100 and 10 mM DMPTB
4. Prepare a blank solution with no DMPTB, repeat step 3 but replace the DMPTB with 50 mM Tris-Cl buffer(pH 7.2 at 20˚C)
5. Prepare 10 mM Tris-Cl buffer (pH 7.5 at 37˚C) with 10 mM KCl
6. Prepare 0.25 M EDTA solution, solubilising with 1 M NaOH

   To perform the assay:

7. Prepare the standard reaction mixture using above solutions: 0.2 mM DMPTB, 0.8 mM DTNB, 1 mM EDTA, 0.17% Triton X-100, 50 mM Tris-Cl buffer, pH 7.5

   Example preparing 3 mL of standard reaction mixture:
   60 µL DMPTB solution
   60 µL DTNB solution
   12 µL 0.25 M EDTA solution
   15 µL 10% Triton X-100
   300 µL Tris-Cl buffer (pH 7.5 at 37˚C)
   2553 µL deionised water
8. Prepare a blank standard reaction mixture by repeating step 7, but replacing DMPTB solution with the prepared blank solution (Step 4)
9. Dissolve enzyme powder in KCl, Tris-Cl buffer solution
10. Load 20 µL of enzyme solution into wells including sample blank wells; add 180 µL of blank standard reaction mixture to all sample blank wells
11. Add 180 µL of standard reaction mixture to all sample wells, preferably simultaneously using a multi-channel pipette, do not re-use pipette tips to avoid bubbles
12. Immediately after pipetting, run microplate reader program:

    Temperature: 37˚C
    Shake: 10 seconds, medium
    Kinetic readout: 30 minutes
    Read: 405 nm
    End kinetic readout
13. Calculate lipase activity from linear section of the readout using a molar absorption coefficient of 13 700 $M^{-1}cm^{-1}$

3.5 Commercial Trials and Launch on Markets.

Following the laboratory based pilot trials for each of the waste sources, where appropriate commercial trials were instigated and the results collated. Often, analyses from the pilot trials were repeated following commercial trials. The results of the commercial trials are also summarised in the aligned appendix.

3.6 Cost benefit Analysis

A cost benefit framework for utilising seafood waste was developed by Ridge Partners and the framework was applied in detail to two of the case studies. Full methodology is available in the relevant appendix.

3.7 Other (not product related) Seafood Industry Waste Reduction

In the initial project (CRC 2013/711: Sub-Program 1) there was an objective to develop, pilot and evaluate at least one new strategy to reduce non-seafood product related processing waste It was considered that non seafood input costs to seafood manufacturing businesses were significant and many companies were looking for assistance to minimize these costs. In this project, CESSH researchers were to work with individual end user companies and use various assessment and research tools to identify and minimize non seafood waste (energy, polystyrene eskies, plastics, ice, wastewater etc). These assessment and research tools were to include:

- Life cycle assessment and economic audits of non- seafood inputs and outputs conducted on individual processing plants/seafood operations. Identification and prioritisation of activities for possible intervention.
- Identification of possible interventions by modelling using life cycle assessment and the economic tool, to understand impacts of interventions on product quality, the environment and costs.
- Trial and evaluate interventions. These interventions may include more carbon efficient equipment, alternative sources of energy, different options for packaging, change of sanitiser and equipment brands and/or implementation of recycling strategies.

An initial audit of waste reduction opportunities was completed and Felicity Denham completed a PhD which incorporated a life cycle assessment on two seafood supply chains, resulting in several recommendations about packaging, energy and water use. Initial work also identified some packaging strategies in relation to the industry reliance on polystyrene: these included recycling (as exampled by the SFM polystyrene recyling unit), use of biodegradable options (High Density polyethylene shopping bags (HDPE), Low Density polyethylene shopping bags (LDPE), PP (polypropylene green bag), Kraft, Calico, Prototype Sud-Chemie box (SSA 2005) and reuseable options (eg tubs, plastic eskies). However, following a review in 2015, no further work was completed in this area.

3.8 Reporting and Extension.

Relevant reporting and extension activities were undertaken.

4 Results and Discussion

4.1 Literature Review and Development of Frameworks

The literature review is attached as Appendix 1.

The framework describing different waste tiers, assisting in defining objectives for the various case study research programs is summarized below.

Tier 1: Efficient, Effective and Legal Waste Disposal (no value add product but triple bottom line benefits).
Tier 2: Simple Value Add: fertiliser, fish meal, hydrolysate, feed components
Tier 3: Complex value add: high quality oil, hydrolysate for pharmaceutical use, pet food.
Tier 4: Premium value add: food, extraction for pharmaceutical additives, food additives, long life food.

Consultation with committed industry partners against outcomes associated with this tiered framework was applied to all case studies for the project.

In addition, a modified value chain analysis framework, developed in previous FRDC/Seafood CRC projects (Howieson *et al.*, 2013; Howieson *et al.*, 2016) was further modified for the processing waste new product development work. This framework is described below:

a. Selection of potential seafood processing waste case studies based on industry consultation/interest.
b. Analysis of possible product outcomes.
c. Demonstration of Whole of chain industry commitment for the new product.
d. New Product Development
    a. Engage the Chain
    b. Understand the Market
    c. Identify new Products and Product in Pilot Laboratory Process (Stop/Go).
    d. Commercial Trials and Cost Benefit Analysis (Stop/Go).
    e. Evaluate market success.

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4.2 Audit of Seafood Processing Waste in Australia

The results of the audit, based in 2013 figures, are shown in Table 2. This table details the production volumes, export and domestic consumption (live/whole) volumes, waste portion (%) and total waste volume for many different sectors. This has resulted in an estimation of seafood processing waste produced in 2013, as a result of Australian product seafood processing. Some limitations of the process are described below.

Table 2. **Seafood Processing Waste in Australia Estimated from Total Production Volumes**

Product	Production volumes (tonne/yr)	Export volume (live/whole)	Domestic consumption (live/whole)	Volume for processing (tonne/yr)	Waste Portion %	Estimated Available Processing waste volume (tonne/yr)
Vessel based processing						
Patagonian Toothfish/Icefish	**?**	**0**	**0**	**?**	**Gills and guts only, frozen at sea then discarded**	**1000**
Abalone (wild)	**4,529**	**2,116**	**2413**	**0**	**68%**	**0 (shucked at sea)**
Scallop	**6,750**	**417**	?	**?(**	**86%**	**0 (generally exported whole or shucked at sea)**
Land –Based processing						
White fish (wild catch + aqua) Snapper Barramundi Mullet Flathead Australian Salmon Spanish Mackerel Other	**60,476**	**1,097**	**-**	**59379**	**59%**	**35,034 (estimate 50% of this volume processed at large establishments = 17, 517).**
Red fish Salmonids (aquaculture)	**44,043**	**4,436**	**-**	**39,607**	**30%**	**12,812.45 estimate 70% of this volume processed at large establishments = 8969)**
Tuna (wild catch)	**8,089**	**3325 (Gilled and**	**4764(Gilled and**		**70%**	**0 (Gilled and**

Product	Production volumes (tonne/yr)	Export volume (live/whole)	Domestic consumption (live/whole)	Volume for processing (tonne/yr)	Waste Portion %	Estimated Available Processing waste volume (tonne/yr)
		Gutted	Gutted			gutted and waste discarded at sea, then marketed whole)
Tuna (aquaculture)	7,486	5315 (G and G)	2171		70%	1,520 (validated by operator of industry waste facility)
Sardine	38,437	0	36515	1,921	70%	576
Shark	5,720	-	-	5,720	40%	2,288
Crab (all species)	4,634	444		380 (estimated by industry)	68%	260
Rock Lobster	10,549	7,526	1,441	1582	57%	902
Prawn – Wild Aquaculture **Total**	 17,403 3,742 **21,145**	3,871	16,410	864 (soft and broken product)	60%	518 (much soft and broken product now processed off-shore)
Abalone (aquaculture)	724	0	474	250	68%	170 (50% shell)
Oyster	12,530	376	11,799	364 (includes not to spec)	86%	313 (~50% shell)
Blue Mussels	3,584		3476	107 (includes not to spec)	86%	92 (~50% shell)
Cephalopods (squid, octopus)	3,485	-	-	3,485	20%	697
Other crustaceans	538	-	-		60%	215
Other Molluscs	4,524	-	Assume 90% (estimated by industry)	452.4	60%	271 (50% shell)
TOTALS						**59111**

The total amount of seafood processing waste was considered to be around 59000 tonnes. The white fish category was found to produce the most amount of waste product at 35,034 tonnes/yr, followed by red fish at 12812 tonnes/yr. As mentioned above however, the white fish category included information classified as "other fish", which could not be differentiated into white and red. In addition the white fish waste figure includes (processing by retailers/consumers and food service who purchase fish whole. Industry experts estimate that ~50% of white fish and 70% of red fish are processed at processing establishments likely to have sufficient waste volume to trial alternative options. As well processing occurring off-shore will further reduce the material available for new waste strategies.

Many of the other categories of seafood produce significantly less waste product during processing due to significantly smaller production volumes to begin with. The sardine category, which is the 3rd largest category in terms of production volume, produces very little waste as the majority of product is used whole as feed for the farmed tuna industry.

Based on all the fish data (shark, sardines, tuna, white fish, red fish) not including off shore or at sea processing, and assuming 50% of white fish and 70% of red fish is processed at establishments large enough to undertake serious activity, the authors estimate that around 31131 tonnes of fish waste is available for significant scale waste transformation activity.

Waste from the mollusc categories is primarily due to product not being to specification and abalone shuckings. Therefore of the total 59111 tonnes, we would estimate that approximately 422 tonnes would be mollusc shell and similar for meat and shuckings.

Crustaceans (lobster, prawn and crabs) are primarily sold on both domestic and export markets as live and/or whole product, with a small amount of soft and broken product going to processing for flesh, with shells discarded. However much of this processing is now occurring off-shore, hence these figures are likely to be even lower than reported here.

The waste figures are estimates with many limitations to the data collection, as described below.

- Production statistics referred to "other fish" in some instances, and hence could not be separated into white fish or redfish categories. "Other fish" were therefore categorised as being part of the white fish category. Similarly, the categories "other crustaceans" and "other molluscs" were used, however, as the "other" species were not identified, the waste percentage could only be estimated by assuming a similar figure to the other related categories.
- In the case of white fish in particular, it is difficult to estimate the location of the processing activity and hence the ability to develop economically viable options based on the waste volume available. Industry experts estimate that ~ 50% of the white fish and 70% of the red fish are processed at a major processing facility, with the other 50%/30% respectively distributed whole for later processing at food service, retail or by the consumer. Waste generated from these smaller operations may require alternative strategies.
- The waste percentage figures for white fish of 59% was an average based on data from different types of white fish that had been analysed. There were differences within this white fish range, with the waste percentage varying from 50% to 75%. Percentages for other seafood lines will also vary.
- For some sectors, some of the data is unclear on the volumes of some products that are exported and/or consumed domestically as whole or live products. This is an important consideration, as this portion of the total catch is not considered to contribute to the waste produced during the processing phase in Australia.
- Proportion of off-shore processing, an emerging trend with Australian seafood businesses, was not estimated, again this would impact on the calculation of the processing waste produced in Australia.
- Insufficient detail on "other" molluscs and crustaceans to generate accurate figures.
- Some seafood production in Australia may have been omitted, and figures may not be always accurate.
- The audit was completed in 2013, and should be updated based on the same framework but with more recent production and market end-point figures.

However it is considered that the methodology could be adopted and modified to update the figures and reduce the limitations. It is noteworthy that trends in the last three years (eg increase in salmon aquaculture and some processing no longer occurring offshore) will impact the figures. Nonetheless this may be the most in depth assessment of seafood processing waste to date.

Seafood processing waste - Industry comments and consultation

The topic of processing waste was discussed with at least 19 (of 40 contacted) seafood processing operations across the different seafood sectors to obtain information about amounts of processing waste, current disposal methods and ideas for investigation into utilising or minimising waste in future. It is noteworthy that some operators were reluctant to discuss their waste information.

Current methods and ideas for future investigation are recorded in Table 3 for each different product type. The results show that currently, fish and seafood waste product in Australia is often being disposed of as landfill, sometimes at a high cost to the processor. Many companies have sought ways to reduce this cost and it is becoming common among processors to be using more efficient and cost effective means of disposal such as selling or donating organic waste to operations such as fertiliser plants, pet food manufacturers, fish feed producers etc.

Table 3. Industry Comments on Current Outcomes for Waste and Ideas for Future Investigation

Product	Current status (waste disposal methods and associated costs)	Ideas for Future Investigation
Fish (Red/White) (Wild catch/ aquaculture)	Fish processed on board – waste (heads, guts etc) disposed of in high seas outside of fishing zone. Large cost per day in time and fuel to dispose of waste product Cheeks, collars can be sold as separate product Frames used as crab bait, frozen and sold to recreational fishers Used to produce fertiliser for agricultural industries. Cost of collection of waste varies with very high cost, although most often collected at no cost to processor by fertiliser companies. Occasionally the organic waste is sold for a small amount. Collected by pet food manufacturers Fish bones used to make stock Waste used as prawn feed for aquaculture Landfill often at high cost to processors Bait for recreational fishermen Tuna waste can be hydrolysed	Look into all the different ways it can be incorporated into other products such as feed, fertilisers and stock Feasibility of bulk fish stock production and how to market to restaurants/chefs and consumers Scales of fish have high Calcium – how can we use/market these in Australia? Utilisation of fish frames – ideas other than stock? Market and profitably of fish oil. What value adding products/techniques will make it worthwhile retaining waste product and keeping on board the fishing vessels (high value products) How to utilise all parts of the fish (new products etc) – high value products that we can produce in Australia Turning waste into liquid to dump underwater within fishing zone – using bio accelerators etc Collaboration between fishermen to research and trial options How can processors reduce costs/ what are the most cost efficient ways to dispose of waste
Crab	Mainly exported live or whole	Extracted as mince for use in reformed value add products (CRC 2014/704).
Abalone (Farmed only)	Guts and viscera collected for compost Shells can be sold to china (cash flow positive) Viscera often frozen and stored (cost to keep on site in cool rooms)	Investigate possible markets for viscera and use of shells in Australia Investigate innovative processing options here in Australia for local businesses to implement – pharmaceuticals, cosmetics etc
Lobster	Mainly exported live, some value- adding, rest to landfill, cost depending on location/region Bait/burley/fertilizer	Value-adding reformed product from, Crushing shells for other uses
Prawn	Mainly whole product, waste is soft and broken, but soft and broken often processed offshore now.	Ideas to utilise prawn heads
Blue Mussels	Product that doesn't meet specifications can be reduced for stock	Hydrolyse waste for fertiliser or other products Enzymatic fermentation for stocks/sauce.

Some processors also use waste to value add to their operations and create new products from what would traditionally be disposed of as waste, while others have found overseas markets for waste in countries where those products are traditionally used to manufacture such things as jewellery, cosmetics and pharmaceuticals.

While surveying the processing industry for waste utilisation ideas to investigate in the future, it was evident that processors are interested in value adding to their business and to the industry as a whole, by looking into the feasibility of new and known products that can be manufactured or produced from seafood processing waste. There was an emphasis on industry collaboration to come up with the best ways to utilise all parts of the seafood product (whole fish/lobster/prawn etc), and come up with high value products that can be manufactured locally in Australia.

The results of the survey confirmed that many seafood processors are interested in operational changes that may result in a return for their waste product as well as decreasing costs and increasing efficiency.

Discussion

The volumes from this audit are less than the 100,000 tonnes previously estimated, likely due to the sector by sector analysis. Some suggestions to further determine the figures include:

- Continually update the figures based on the audit framework developed, as some trends have changed (eg increased production of farmed red fish, move to more Australian based processing)
- Better understanding of the fate of white fish and red fish to processors, or direct to retailers, food service etc. This will allow a more accurate determination of the white fish and red fish waste for potential for economic revised waste strategies.
- Better understanding of the proportion of off-shore processing for more accurate representation of seafood processing waste remaining in Australia.
- Better understanding of the proportion of live/whole product marketed for each of the sectors.
- Further conversation with processors to verify the data that has been obtained.

The waste volume data collected assisted in early prioritisation of activity areas for the project. Some of these activity areas included:

a. Assessing opportunities for finfish waste
b. On board processing waste for Patagonian Toothfish and other operations where there are restrictions on where the waste can be discarded.
c. Adding value to ranched Southern Bluefin Tuna waste (with the potential to develop a facility able to cater for other sectors during the non-tuna harvest season).
d. Farmed abalone shucking waste.
e. Other shellfish waste

The data does indicate that shark waste may represent an opportunity, however this was addressed as part of an aligned project FRDC 2014/704: Waste Transformation for the Catering Market.

The red fish waste represents an opportunity but it was understood that “in company” research activity and facility development was being undertaken for this sector.

4.3 Industry Consultation and Development of Potential Opportunities and Defined Industry Partners.

The “group explorer” project priority setting workshop commenced with surfacing challenges and opportunities for the industry which were subsequently clustered – the clusters comprising: marketing, governmental regulations and compliance, costs, labelling and waste. It was agreed that the first three of these were for the most part outside of research remit required for leveraging the funding available and the fourth, labelling, was already in process.

The group thus began to explore the cluster focusing on waste and determined that there were potentially 5 research projects embedded within the material. Each of these was subsequently reviewed and elaborated in terms of possible actions before each organisational member noted which project(s) they were prepared to support (financially and/or in terms of time). As a result a series of case studies were identified for the project.

Hence, the initial case studies, developed in 2013, are summarised below:

- SAMPI: Improved quality of hydrolysate and oil from tuna waste.
- Austral Fisheries: on board treatment of Patagonian Toothfish to facilitate legal disposal at sea or simple value adding.
- Sydney Fish Markets: Efficient/effective stabilisation and transport/disposal of processing waste and simple value adding.
- Southseas Abalone (Ausab): Develop cost effective process of removing viscera from the abalone shell so as to reduce the amount of viscera going to landfill. Develop cost effective process of converting viscera into a liquid that can be frozen and sold as food additive. Develop cost effective process of converting viscera into a powder that can be used as food additive. Develop cost effective process of converting viscera into a powder that can be capsulated and sold as health food/medicine. Identify high value functional components in abalone viscera.
- Fremantle Octopus: investigate extraction of oil from octopus waste (cf squid oil), new outcomes for octopus heads.

As the project progressed, through direct contact by industry to the Principle Investigator and following a further multiple stakeholder consultation in 2015, new case studies were identified. These case studies included

- Biomax Singapore: the suitability of fish waste for producing high value fish feed meal or compost through a unique enzyme hydrolysis and drying process.
- Kinkawooka Blue Mussels: hydrolysis of out of specification Blue Mussels to produce a Blue Mussel stock.
- Westmore Seafoods: development of a Scampi roe product.
- Paspaley Pearls: Premium market opportunities for peal meat adductor muscle.
- Australian Dried Seafood: research to optimise processes to produce dried swim bladders/fish maw.
- Fins Seafood Retailers (later extended to other independent seafood retailers): understanding of waste challenges for independent seafood retailers, and development of strategies for such operators.

It is noteworthy that some of the later studies were requested from interstate, likely due to extension activities undertaken for the project. It is also noteworthy that the Principle Investigator continues to receive regular enquiries about new case studies from the Australian seafood industry.

4.4. Laboratory/Pilot Scale Trials

The range of cases studies subject to laboratory/pilot scale experiments are summarised below, with detailed product and company specific reports available as appendices. If commercial scale activities were undertaken these are described in Section 4.5. Table

4.4.1 SAMPI tuna hydrolysate

SAMPI, a Port Lincoln based company produced an acid hydrolysate organic fertiliser product from Southern Bluefin tuna waste (Figure 8).

The first series of laboratory experiments were conducted to look at strategies to optimise oil extraction and recovery following the hydrolysis process, with a view to developing a separate tuna oil product as well as standardising the level of oil in the hydrolysate to at or just below 5% hence opening up new markets as an aquaculture feed. Whilst quality and quantity of oil extracted could be improved these experiments were subsequently ceased as the oil levels were generally inconsistent and too low to develop an economically feasible process.

The second set of experiments optimised commercial enzyme rather than acid hydrolysis for an improved quality product. These experiments were successful, particularly using alcalase as the commercial enzyme (see Appendix 2). It is perhaps noteworthy that a Curtin PhD student is currently investigating the use of the SAMPI tuna enzyme hydrolysate as a partial fish meal replacement for juvenile Barramundifeed. Early results indicate that with some replacement of feed ingredients with hydrolysate improvements in growth and immunity were recorded. This work is continuing.

The third set of experiments were undertaken to investigate options for hydrolysing the gill plates of the tuna and also to investigate commercial opportunities for the fish bones, a by-product of the hydrolysis process (Appendix 3). Whilst hydrolysing, drying and other extraction processes were developed, at this stage options for gill plates and bones end-uses do not appear commercially feasible processes.

SAMPI Natural Marine Products

www.sampi.com.au

Figure 8 SAMPI logo and tuna waste before hydrolysis

4.4.2 Austral Fisheries Patagonian Toothfish Waste.

This case study investigated on board strategies to transform Patagonian Toothfish (*Dissostchus eleginoides)* waste. Austral process the Patagonian Toothfish at sea and heads and intestinal waste are discarded at some distance away from the fishing grounds. This costs the company in terms of fuel costs and lost fishing time whilst travelling to the “discard” zone. Enzyme hydrolysis of the waste was investigated and compositional studies undertaken of the hydrolysed fractions. Effective hydrolysis (see Figure 9 for hydrolysed waste) was achieved and a report, including preliminary costings was provided to the company (Appendix 4) for operational assessment. In addition, the Principle Investigator of the project was contacted by Proctor and Gamble, a large detergent company in the United Kingdom, in regard to sourcing cold tolerant enzymes for detergent addition. Preliminary extraction and activity studies at Curtin University (Appendix 5) showed lipase and protease activity. Freeze dried enzymes were despatched to the Proctor and Gamble technical team for further assessment with comments from the technical director summarised below:

Please find attached stain removal data on the toothfish enzyme, we’ve evaluated this across a range of stains many of which are known to be sensitive to enzymes – particularly protease, amylase and lipase. We ‘ve evaluated the toothfish enzyme vs a regular enzyme system in a detergent. Unfortunately we don’t see the toothfish enzyme (tested at 3 levels) make any real improvements in stain removal vs the nil enzyme reference. There are a few possibilities as to why, the main two are (i) the enzymes are not stable in the presence of detergent chemistry in a wash process – especially surfactant or, (ii) the enzyme has lost activity during the shipping process.

Figure 9 Patagonian Toothfish hydrolysis fractions following sitting for 24 hours

4.4.3 Ausab Farmed Abalone Waste.

This case study investigated initially hydrolysis (not successful) and later drying and grinding of farmed abalone shuckings (Appendix 6). Hydrolysis was unsuccessful but a dried abalone powder was produced (Figure 11) and despatched for compositional analyses. The powder was microbiologically safe and shelf-stable for up to twelve months but cadmium levels were close to FSANZ limits. The report was provided to the company for assessment and further action. The Principle Investigator has recently been contacted by a different farmed abalone group requesting similar research be undertaken.

Figure 11 Dried and Ground abalone shuckings

4.4.4 Fremantle Octopus Waste

Octopus heads and intestinal waste were examined for oil extraction and other uses (Figure 12). However, this work was ceased in the preliminary stages as hydrolysis and extraction trials indicated such activity would not be commercially viable.

Figure 12 Extracted Octopus Stomach and Offal

4.4.5 Sydney Fish Market Waste

This case study was not pursued due to the loss of key supporting personnel from Sydney Fish market.

4.4.6 Biomax Pty Ltd Trials.

The Principle Investigator was approached by Biomax Pty Ltd, a Singaporean company who had developed a unique enzyme driven composting and drying process that resulted in a shelf-stable dried product in 24 hours. The company was interested in co-funding some fish waste trials through their process and then follow up with assessment of the dried product as a feed ingredient. Successful trials were undertaken with Snapper, Atlantic Salmon and Patagonian Toothfish waste and compositional analyses completed (see Appendix 7) (Figure 13). A database of Australian feed producers were developed and results were provided to such companies for comment as potential feed ingredients. Significant cost, nutritional and formulation issues were identified by the feed companies, these responses were recorded. A summary report was provided to BIomax Pty Ltd for comment.

Figure 13 Fish waste before and after BIomax composting process.

4.4.7 Kinkawooka Blue Mussels Stock

Kinkawooka Blue Mussels requested a case study to look at optimisation of Blue Mussel stock production from second grade Blue Mussels (Appendix 8). A multiple enzyme driven hydrolysis process was developed, and sensory assessment undertaken of the resulting Blue Mussel stock product (Figure 14). A pleasing product was developed at laboratory scale and was despatched for market feedback. The report is available on request from the Principle Investigator.

Figure 14 Various Blue Mussel stock samples

4.4.8 Westmore Seafoods Scampi Roe.

Westmore Seafoods requested an investigation into the development of a value-added product from scampi roe (Figure 15). Curing trials were undertaken, laboratory scale production protocols optimised for sensory quality. Shelf-life and composition analyses were undertaken on the product produced in the laboratory. The report (Appendix 9) was provided to the company for further action and is available on request from the Principle Investigator.

Figure 15 Scampi roe

4.4.9 Paspaley Pearls Pearl Adductor Muscle Product.

Paspaley Pearls were interested in commercialising production of the adductor muscle, a by-product of the pearl harvesting process. Samples of fresh and frozen pearl meat were subjected to different packaging and cold storage treatments and then analysed for sensory assessment and for shelf-life (Appendix 10 and 11) (Figure 16). Optimised procedures were then forwarded to the company, who subsequently purchased the appropriate shipboard processing equipment and developed protocols for addition to production documents for export and domestic markets. Such protocol are now being assessed by regulatory authorities with launch of the new products for the domestic and local markets expected in 2018.

Figure 16 Paspaleys Pearl meat (adductor muscle)

4.4.10 Dried Seafood Corporation and Aquabotanica Dried Fish Maw

Aligned companies Dried Seafood Corporation and Aquabotanica requested investigation of optimisation of the production of oven dried swim bladders (fish maw) from initially Barramundi (Appendix 12) (Figure 17) and subsequently a range of fish species including Jewfish, Mulloway and Ocean Cobbler (Appendix 13). Microbiological load reduction using chlorine dioxide was optimised as were drying conditions. Food safety and shelf-life analyses were completed and visual comparisons with sun dried, imported product undertaken. The report was provided to the company, along with some samples for market assessment. The company has purchased a commercial dryer and has indicated conducting of an economic and logistical evaluation prior to possible commercialisation is underway.

Figure 17 Dried Barramundiair bladders

4.4.11 Waste Options For Small Seafood Retailers Waste Management

In response to a number of enquiries from smaller seafood retailers about waste transformation options, small scale enzyme hydrolysis trials were completed on a range of species commonly sold in small retailers. These trials include Snapper, Barramundi and Atlantic Salmon. Subsequently a survey was completed with small seafood retailers about their waste (Appendix 14). The survey results indicated an interest in a solution to produce other products from waste on site, and hence a small scale hydrolysis unit, suitable for small retailers was designed by the research team and construction commissioned (see Figure 5). Whilst still being trialled, the unit has been used successfully to transform mixed product from a small retailer, and will also be used to produce enzyme hydrolysate for juvenile Barramundi feeding trials being conducted by PhD student Muhammad Abu Bakar Siddik. Trials with the hydrolysing unit will therefore be continued past the reporting stage of the project.

4.5 Commercial Trials and Launch on Markets

Table 4 summarises the products from the project that have been commercially trialled, and in some cases launched on the market.

Table 4: Commercial Trials and Outcomes from FRDC 2013/711.40

	Current Status	**Future Commercial Activity**
SAMPI enzyme produced hydrolysate.	Factory modifications have occurred and enzyme hydrolysis process has been implemented in factory. Volumes of new product is currently unable to meet demand. Yellowtail kingfish as well as tuna product undergoing enzyme hydrolysis.	Company is investigating further sources of raw material to increase production when tuna is not being harvested. Current tuna harvest season is April to
SCAMPI Roe	Pilot Commercial trials and costings completed. Product now commercially available on market.	Product is in demand and expensive (~$3000/kg).
Paspaleys Pearl meat	Domestic and export certification, processes, protocols, premium packaging development and marketing studies underway prior to launch	If all approvals received, product likely to be launched on domestic and export markets in 2018.
Small Hydrolysis unit for small seafood retailers	Small unit commissioned and in trials.	Continued interest from small seafood retailers on results with unit. Further units may be constructed, with modification once pilot trials completed.
Patagonian Toothfish	Following discussions with engineers, operational issues associated with heating, separation and liquid enzyme storage were identified. However the results will be included in a Curtin ARC Linkage project to look at shipboard waste solutions. Patagonian Toothfish enzymes have been extracted for assessment by Proctor and Gamble.	Assessment of enzymes for potential use in cold water detergents by Proctor and Gamble.
Kinkawooka Blue Mussel stock	Commercial trials completed at Kinkawooka facility in Port Lincoln and preliminary cost	If market acceptability ensues and positive cost benefit then product likely to commercialised.

	Current Status	Future Commercial Activity
	benefit analyses conducted. Samples from commercial trials have been provided to potential markets of feedback. Further adoption has been delayed due to structural changes to company.	
Dried Seafood Corporation	Samples being assessed for market suitability.	Commercial drying unit purchased but installation will depend on market assessment.

4.6 Cost Benefit Analysis

The cost benefit framework developed and the results of the cost benefit analysis undertaken for two of the case studies: SAMPI tuna hydrolysate and Paspaleys Pearls adductor muscle product are reported in Appendix 15. Pending industry agreement this report can be made available on request.

Parts of the executive summary from the report is reproduced below.

This report presents two Cost-Benefit Analyses (CBA) for selected Australian seafood waste case studies. Seafood waste streams offer commercial opportunities for value adding and coproduct development, in either seafood and or related industrial product markets. Dr Janet Howieson, on behalf of Curtin University, is working with the two commercial seafood processors to assess, develop and implement ways to better utilise and commercially monetise their respective seafood waste streams.

This project evaluates the two waste stream case studies (Paspaley Pearling Company, and FishTrade International) from a commercial cost-benefit viewpoint. The report summarises these cases and their commercial prospects. The report also presents a standard cost-benefit template to guide similar evaluations.

The CBA Project Team comprised staff from each case study enterprise, a project manager from Curtin University and a consultant from Ridge Partners, a Brisbane based consultancy.
A multi-stage methodology was implemented in 2016-17 to undertake these CBAs using standard CBA procedures. The analysis was completed in early 2017 based on discussions of existing processing activities and assumptions developed jointly with the companies.

The analyses have established and analysed estimated CBAs and a number of key variable sensitivities over a ten-year investment horizon. The CBA has taken a very conservative approach by limiting the analyses to only those impacts and net benefits derived from the investment, that are identifiable on the supply-side, operationally compelling, and financially quantifiable as a cash flow to the company within the ten-year horizon. Other potential and significant net benefits during and beyond the ten-year horizon from sources such as competitive advantage, food safety, or changing market demand have not been incorporated into these CBAs. Any related benefits derived by the companies from their supply chain partners have not been included.

Key financial assumptions in the “Before change” analysis have been very conservative. Nominal costs (i.e. cash outflows unadjusted for inflation) for both CBAs are assumed to escalate at 2.5% p.a. while nominal benefits (i.e. cash inflows) are not adjusted for inflation.

Based on assumptions listed and data provided by the companies, these Cost Benefit Analyses found that : Paspaley Pearling Company's proposed upgrade of its pearl meat by-product waste stream into a value-added food service offer in Asia and Fish Trade International's proposed upgrade to its seafood waste plant and market approach would both create a positive net present value and a positive internal rate of return over10 years. Analysis of the investment sensitivities for both CBAs indicates that the proposed ventures are moderately sensitive to changes in output product prices and volumes. Pending industry agreement, the final report (Appendix 15) is available on request from the Principle Investigator.

This framework can now be applied to other similar waste utilisation initiatives in the future. As an example it will be used in the cost benefit analyses to be conducted as part of FRDC 2016/261: Options for Carp Biomass Utilisation.

4.7 Reporting and Extension

4.7.1 Extension Activities

Table 6 summarises the extension activities and Publications from the project.

Table 6 Extension Activities and Publications from FRDC 2013/711.40

Publication/Product	Detail	Status
Magazine Article	Seafood waste management adds value	Seafood CRC Magazine Published July 2014
Conference abstract	World Seafood Congress, Grimsby 2015: New Opportunities for Seafood By-Products: An Australian Perspective.	Delivered by Janet Howieson September 2015
Presentation	Industry Perspective: Fisheries' (invited) RIRDC Food loss workshop, Canberra, April 24th 2015.	Invited presentation by Janet Howieson
Collaborative discussion	As part of ACACA funded trip to China, lengthy discussions with Chinese processing companies and scientists in regard to waste utilisation.	Janet Howieson was a participant on ACACA mission (May 2015).
Conference abstract (oral)	Australia Asia Food Innovation Conference Perth 2016: Fish Waste As A Potential Aquaculture Ingredient	Delivered by Kerri Choo in March 2016
Conference abstract	AIFST National conference (Brisbane) High protein opportunities in seafood (invited)	Delivered by Janet Howieson in June 2016
Conference abstract	Food Engineering 2016: The role of enzymes in value-adding to seafood processing waste.	Delivered by Kerri Choo in November 2016
Industry Magazine article	New Value from Seafood	FISH September 2016
Media article(s)	http://www.abc.net.au/news/2016-10-26/Patagonian Toothfish-offal-might-be-	October 2016

	used-in-detergent/7967278	
Industry Presentations	WAFIC Board CESSH industry group.	February 2015 September 2016
Federal Government Briefing	Briefing on Project Outcomes to staff developing strategy for National waste Reduction Initiative (Environment Standards Division, Department of the Environment and Energy).	August 2017

4.7.2 Post-Graduate Student Projects

Operational funding from this project was used to assist with the cost of consumables for fish waste research projects undertaken by three Masters of Food Science and Nutrition students and one Honours student. Dr Howieson co-supervised these projects. In addition Dr Howieson co-supervised Felicity Denham who completed her PhD on Environmentally Sustainable Seafood Supply Chains : Analyses, Issues and opportunities and is also supervising Muhammad Abu Bakar Siddik is who is currently completing his PhD: Physiological and immunological responses of juvenile Barramundi (*Lates calcarifer*) fed bio-processed animal based protein diets. As a result hydrolysates produced enzymatically from the waste from various common fish species are being tested as replacements of fish meal in juvenile Barramundi feed. Further details of these student projects are below, the student project outputs are also summarised in the relevant report to industry.

Details of all student projects are below:

- Felicity Denham (PhD) Environmentally Sustainable Seafood Supply Chains : Analyses, Issues and opportunities (completed 2015).
- Abubakary Saad Mbadjo (Masters of Food Science, research project) (with Dr Ranil Coorey) Production of high protein biscuits from dried fish frames (2014).
- Duc Minh Nguyen (Masters Food Science and Technology) (with Dr Ranil Coorey): Utilize fish waste for fish snack production (2016)
- Ahmad Jauhari (Masters Food Science and Technology) (with Dr Ranil Coorey) Fish protein extraction from Patagonian Toothfish by-products using the modified endogenous enzymatic method (2016)
- Caleb Joshua Chingcuanco (Honours) (with Dr Ranil Coorey): Optimisation of the Formulation and Processing Parameters of Blue Mussel Shell Sauce Processing (2015)
- Muhammad Abu Bakar Siddik (PhD) (with Prof Ravi Fotedar) Physiological and immunological responses of juvenile Barramundi (*Lates calcarifer*) fed bio-processed animal based protein diets (ongoing).

5. Conclusions

This report summarises the outputs of FRDC 2013/711.40: New Opportunities for Seafood Processing Waste. An audit of the different forms and feasibility of access for seafood processing waste in Australia has been conducted, likely to be the most accurate assessment thus far, and allows more informed evaluation of potential economic opportunities from seafood processing waste. Industry comment from the survey was also an important outcome, demonstrating that many companies are committed to investigating new methods to treat the processing waste.

Industry commitment to waste transformation was indicated by the total of eleven industry driven requested case studies were commenced, and are reported here. A variety of different waste transformation techniques were trialled including enzyme and acid hydrolysis of frames, offal and bones, curing of roe, drying and milling, enzyme extraction, oil extraction, composting and flavoured stock production. As a result a variety of products for different outcomes were produced, and compositional and shelf-life analyses completed on each of them. Three new products have been subsequently commercialised and a number of other products are in market/commercial trials. Positive cost benefit analyses long term were identified for two of the commercialised products.

The results of the project have been extended in a variety of both industry specific and academic written and oral formats. A generic framework for approaching similar research in the future has been formulated, new seafood waste treatment methodologies have been developed and proof of concept shown for several commercial case studies. A number of post-graduate students have been trained in seafood waste transformation. The project findings have been incorporated into the development of new waste research (eg Fight Food Fraud and Waste CRC Bid, ARC Linkage application) and policy (eg National Waste Reduction Strategy) waste research and policy initiatives.

In conclusion it was clearly evident that the Australian seafood industry generally is looking at new ways to utilise processing waste, as shown in the industry interest and commitment to the various case studies undertaken as part of the project. It is noteworthy however that successful launch, even of a novel market acceptable product, is influenced by market acceptability, cost benefit analysis and the inherent and timely ability of the company to undertake commercialisation.

6. Recommendations

Due to continued and increasing interest in the area of seafood waste transformation, it is recommended that

a. The seafood processing waste audit methodology developed is regularly modified for improved accuracy and updated.

b. Consideration is given to investment in further research opportunities for the Australian Seafood industry to generate opportunities from seafood processing waste.

c. Consideration is given to policy/investment support for companies committed to developing strategies to utilise seafood processing waste.

Appendices

Appendix 1 Literature Review

Appendix 2 SAMPI Tuna Hydrolysate Production

Appendix 3 SAMPI Tuna Hydrolysis Process: Options for Tuna Bones

Appendix 4 Investigation of On Board Strategies To Transform Patagonian Toothfish (*Dissostchus eleginoides)* Waste

Appendix 5 Patagonian Toothfish digestive enzyme purification and activity characterisation

Appendix 6 Strategies for Potential Utilisation of Aquacultured Abalone Waste

Appendix 7 Investigation of Biomax Process For Hydrolysing Seafood Waste

Appendix 8 Kinkawooka Blue Blue Mussel Stock: Optimisation of Blue Mussel Stock Production Using 2nd Grade Blue Blue Mussels

Appendix 9 Scampi Roe Product Development

Appendix 10 Paspaley Pearl Meat: Fresh v Frozen Pearl Meat Quality

Appendix 11 Paspaley Pearl Meat: Frozen Pearl Meat Shelf Life Determination

Appendix 12 Barramundi Swim Bladders: Optimisation of Sanitising, Cleaning And Drying Of Air Bladders For Human Consumption

Appendix 13 Small Scale Dehydration of Air Bladders from Different Species Of Fish To Produce Fish Maw

Appendix 14 Small Seafood Retailers: Waste Survey and Options

Appendix 15 Cost Benefit Analysis Report.