Appendix F Case study: Aquaculture feed and prawn breeding

SUMMARY OF KEY FINDINGS

CSIRO's research and development on prawn breeding and feed has led to:

- Improved productivity
  - Prawns that grow faster, have a more consistent size and are more resistant to common viruses.
  - Ponds stocked with CSIRO's selectively bred prawn broodstock had a 39 per cent increase in productivity compared to ponds stocked with wild stock.
- A more sustainable prawn industry
  - The prawn feed additive Novacq™ is made using agricultural waste and removes the need to use fish meal or fish oil obtained from the wild fish resources.
  - Prawns that are fed the additive are healthier and grow 30-40 per cent faster.

The uptake of the new prawn breeds has been rapid and significant to date and is expected to track the projected expansion in the industry. Benefits delivered to the industry to date are estimated to be around $73.5 million. Of this, 75 per cent, or $55.1 million, are attributable to CSIRO. ACIL Allen estimates that CSIRO's prawn breeding project will deliver total additional benefits of $452.5 million under a 5 per cent discount rate between now and 2023/24, of which 75 per cent or $339.4 million are attributable to CSIRO.

Use of Novacq™ only began during the last year so benefits to date are small. However there is very strong interest in licensing of the technology and this (plus the demonstrated benefits of the feed) is expected to drive strong uptake in Australia and overseas. ACIL Allen estimates that the cumulative benefits from the use of the novel prawn feed will be around $368.3 under a 5 per cent discount rate between now and 2023/24. In addition, CSIRO is expected to earn over $100 million in royalties from the domestic and overseas sale of Novacq™.

This adds up to total benefits of $882.2 million attributable to CSIRO, including royalties revenue.

F.1 Introduction

F.1.1 Purpose and audience

This independent case study evaluation has been undertaken to assess the economic, social and environmental impact of CSIRO research on prawn breeding and sustainable aquaculture feed. This case study has been prepared so it can be read as a standalone report or aggregated with other case studies to substantiate the broader impact and value of CSIRO's activities.

The report is provided for accountability, reporting, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

F.1.2 Background

Wild prawn stocks are under pressure from overfishing

About half the prawns consumed in Australia are imported from overseas, for example from Vietnam and China. Global stocks of wild prawns have been under increasing pressure in recent years, as a result of overfishing. A 2009 report by the Food and Agriculture Organisation (FAO) pointed to serious overfishing of shrimp populations and associated environmental degradation in the majority of selected case study countries (although

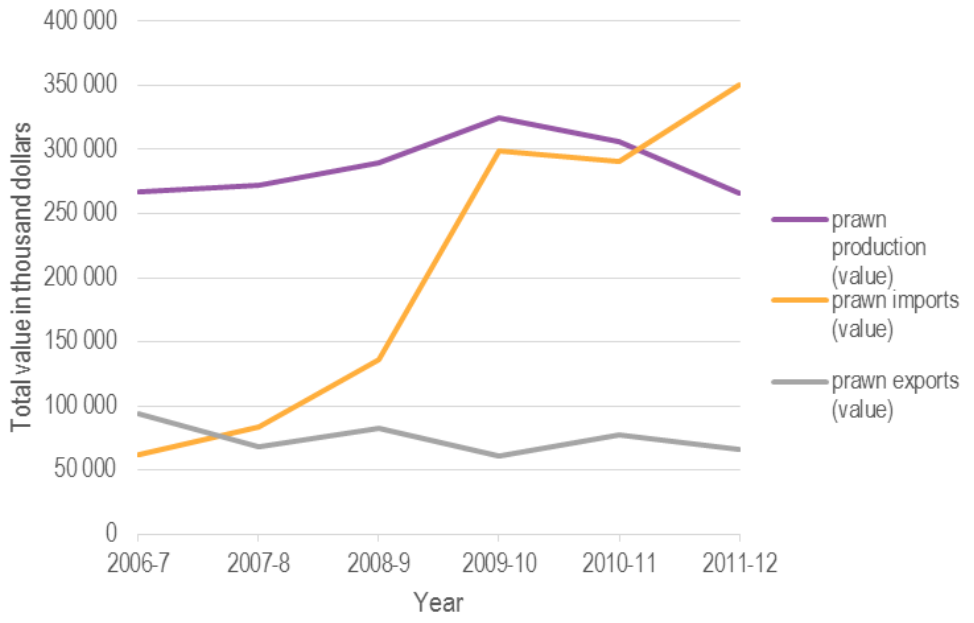
Australian prawn fisheries were ranked as some of the best managed of the countries surveyed in the report) due to capture of juveniles, coastal habitat degradation, illegal trawling, the destruction of seagrass beds and large volumes of non-shrimp by-catch, which is often thrown away (FAO, 2009).

Globally FAO estimates that in 2011, 28.8% of the world's fisheries were overfished, with another 61.3% of fish stocks fully fished (and therefore vulnerable to overfishing) and 9.9% of global fish stocks under fished (FAO, 2014).

Farmed prawns supply a growing share of Australia's demand

In Australia, wild caught prawns continue to comprise a large percentage of total prawn production, accounting for 77.8 per cent of the total dollar value of Australia's prawn production, which stood at $266.2 million, in 2011-12 (ABARES, 2013) (see Figure F1). In response to the decline in the stocks of wild prawns there has been a significant increase in the use of farmed prawns to meet consumer demand. While prawn imports account for a high proportion of total consumption in Australia, Australian produced prawns generally attract a higher market value. In 2011-12 the average price of imported prawns was $9,350/tonne. The average price for exported Australian prawns was $12,360/tonne, while the price of Australian wild prawns for the domestic market was $10,037/tonne. The domestic farm gate price for Australian farmed prawns in 2010-11 was $14,540/tonne (APSQ 2012).

Figure F1 **Australia's prawn production and trade by dollar value**



Source: ABARES 2013, 2010

CSIRO has two streams of prawn research …

In 2002 the CSIRO Future Foods flagship and its partners began its research to improve the sustainability and productivity of Australia's prawn industry. That research had two streams of activity, namely, prawn breeding and novel prawn feed.

Prawn breeding

… one is prawn breeding …

One of the primary tools for boosting productivity in the agribusiness sector is to use selective breeding to develop faster growing and or more disease-resistant species. CSIRO has undertaken a considerable amount of work into the domestication and selective breeding of the *Penaeus monodon* species of prawn (black tiger prawns). One aim of this

research was to domesticate *P. monodon*, eliminating the need to use wild caught prawns as broodstock to produce each new generation of farmed black tiger prawns. A second objective of this research was to develop a prawn with improved growth, survival and feed conversion rates as well as improved tolerance towards endemic prawn viruses.

Novel prawn feed

… the other is a novel prawn feed

Traditionally, fishmeal and fish oils have provided a major component of the prawn feed used in prawn aquaculture. However, the reliance on fish products for inclusion in prawn food has in turn caused a number of problems. Wild fishery sources have been an important source of fish-based prawn feed, which has put further strain on fish stocks and raised questions about the long-term sustainability of prawn aquaculture.

Until recently practical replacements for fishmeal and fish oils were largely ineffective as they were unable to provide the nutrition required to quickly grow large prawns that are able to compete in the market with prawns grown on feed that is based on fish products (Glencross *et al.*, 2014).

F.1.3 Approach

The approach taken in this case study is based on CSIRO's impact framework and aligns with the nine-step process described in the CSIRO's impact evaluation guide, namely:

1. Initial framing of the purpose and audience of the impact evaluation.
2. Identify nature of impacts (*what is the impact pathway, what are the costs and benefits*)
3. Define a realistic counterfactual (*what would have occurred in the absence of CSIRO*)
4. Attribution of research (*CSIRO vs. others' contribution*)
5. Adoption (*to date and in future*)
6. Impact (*timing, valuation, distributional effects among users, effects on non-users*)
7. Aggregation of research impacts (*within program of work*)
8. Aggregation of impacts (*across program of work*)
9. Sensitivity analysis and reporting.

Note that steps 7 and 8 above are less relevant for this individual case study as the prawn breeding and novel feeds projects are being considered in isolation. The impacts identified in this case study will be aggregated with those from other aspects of CSIRO's work to provide an insight into the overall benefits arising from the Organisation's work.

F.1.4 Project origins and inputs

The objective of CSIRO's Food Futures Flagship is:

> Transform the international competitiveness of the Australian Agrifood sector, adding $3 billion in annual value, by applying frontier technologies to high potential industries (CSIRO, 2014a).

The future *animal breeds and feeds* theme of work specifies its objective as being:

> To boost the value of our seafood and livestock industries through breed engineering and leading edge production technologies.

Prawn R&D will contribute to the Food Futures Flagship's objectives

The Food Futures Flagship roadmap states that the objective of this work is to boost the value of Australia's animal-based food industries by $350 million per annum for beef and $550 million for seafood over the next 10 plus years (CSIRO, 2013).

CSIRO's research into prawn breeding and prawn feed has made an important contribution to the Flagship's goal both through the development of a prawn breed that grows faster and

is more resistant to prawn diseases, and through the development of a new and more sustainable prawn feed additive.

History of project

CSIRO's expertise built up over 20 years

During the past 20 years CSIRO has worked closely with the Australian and international prawn farming industry to undertake research on a range of issues that are critical to that industry, including: environmental and health management; selective breeding; domestication; and nutrition.

Over that time CSIRO has established an excellent international reputation for its expertise in the selective breeding of farmed prawns. CSIRO has also developed novel prawn feeds that will help break the existing reliance of the prawn industry on wild fisheries as a source of prawn feed.

Project inputs

About $28 million spent on prawn R&D over last 10 years

CSIRO's inputs into the two streams of research, including labour and operating costs, are outlined in Table F1.

Table F1 **CSIRO support for prawn related R&D**

Date	Prawn breeding ($million)	Prawn feed ($million)
2004-05	1.20	0.85
2005-06	1.23	1.20
2006-07	1.22	1.35
2007-08	1.23	1.27
2008-09	1.25	1.40
2009-10	1.00	1.01
2010-11	1.20	0.80
2011-12	1.30	0.83
2012-13	1.20	0.99
2013-14	1.10	0.39
Total	**11.93**	**10.10**

Source: CSIRO

CSIRO has also benefitted from in-kind support from its industry partners in the prawn farming sector, who offered the use of their prawn stock for CSIRO to conduct its prawn breeding research project.

Industry has provided financial and in-kind support

External funding and in-kind support from other sources is shown in Table F2 and Table F3 respectively.

Table F2 **External support for prawn related R&D (cash co-invested)**

Date	Prawn breeding ($million)	Prawn feed ($million)
2004-05	.26	0
2005-06	.25	0
2006-07	.20	0
2007-08	.35	.2
2008-09	.27	.15
2009-10	.16	0
2010-11	.24	0
2011-12	.37	.4
2012-13	.54	.26
2013-14	.40	.50
Total	**3.04**	**1.51**

Source: CSIRO

Table F3 **External support for prawn related R&D (in-kind)**

Date	Prawn breeding ($million)	Prawn feed ($million)
2004-05	.09	0
2005-06	.08	0
2006-07	.07	0
2007-08	.12	.1
2008-09	.09	.07
2009-10	.05	0
2010-11	.08	0
2011-12	.12	.2
2012-13	.18	.13
2013-14	.13	.18
Total	**1.03**	**.69**

Source: CSIRO

F.2 Project activities

Prawn breeding

Broad spectrum of CSIRO capabilities used

CSIRO brought together a number of its core capabilities to use in its prawn breeding project. These are listed in Table F4.

Table F4 **CSIRO prawn breeding project capabilities and activities**

Capability	Activity
Breeding system management	Established a captive breeding management system to enable selective breeding of domesticated *P. monodon.*
Software development	Developed sophisticated databases and software systems to enable accurate tracking of prawn pedigree, mate allocation, controlling inbreeding and selection for desirable genetic traits.
Molecular virology	Identified and characterised prawn viruses and their interaction with selectively bred prawns, enabling selective breeding for disease resistance. This was achieved through the development of simple virus testing kits that can be used on-farm to test each individual prawn for its breeding suitability.
Molecular genetics	Developed genetic markers to monitor genetic diversity, control inbreeding, optimise mate allocation and locate genes that control traits of commercial interest.

Capability	Activity
Quantitative genetics	Analysed estimated breeding values (EBVs) to optimise selective breeding of economically important traits.
Media communications	CSIRO made media outreach a core part of its strategy to increase awareness among the prawn industry and boost adoption rates. CSIRO undertook a concerted media campaign in 2010, which saw coverage of domestication and breeding of the black tiger 'super prawn' in major Australian news outlets such as the ABC, the Sydney Morning Herald and Channel Nine, among others.

Source: ACIL Allen Consulting; CSIRO

These capabilities were first applied in CSIRO's work with Australian prawn farmers in the domestication and selective breeding of *P. monodon* black tiger prawns. In addition, CSIRO took the lessons learnt from its Australian black tiger prawn breeding project and applied that newly developed knowledge and the related technology skills to *Litopeaneus vannamei* (Pacific White Shrimp) breeding in Vietnam, in cooperation with a local Vietnamese industry partner.

Prawn feed

CSIRO's prawn feed is more sustainable than alternatives

The world has long been looking for a sustainable alternative to conventional fish based prawn feed. CSIRO researchers have developed a way to take any source of high-volume, low-cost agricultural product like rice-bran and then use marine microbial processes to turn it into a feed supplement that when harvested and dried can be given to prawns.

CSIRO brought together a range of core capabilities for its prawn feed project. These are shown in Table F5. It is worth noting that using CSIRO's media communications capabilities were an essential part of its strategy to increase awareness of the outcomes its R&D into novel prawn feed and prawn breeding and thus help drive more rapid adoption by industry.

Table F5 **CSIRO novel prawn feed project capabilities and activities**

Capability	Activity
Microbiology and nutrient dynamics	Modelling nutrient dynamics and controlling the production of marine microbial biomass
Organic chemistry	Characterisation of bioactive compounds
Crustacean nutrition	Determining the dietary requirements of crustaceans and formulation of feeds containing Novacq™
Feed technology	Optimising the production, harvesting and processing of Novacq™
Media communications	CSIRO made media outreach a core part of its strategy to increase awareness among the prawn industry about the benefits of Novacq™. CSIRO undertook a concerted media campaign over the second half of 2013 and into 2014, which saw coverage of Novacq™ in major Australian news outlets.

Source: ACIL Allen Consulting; CSIRO

Current strategy period

CSIRO is engaged in ongoing research designed to extend the benefit of its prawn breeding and novel feeds research project.

F.3 Project outputs

F.3.1 Key outputs of the project

Prawn breeding

CSIRO has bred a healthier and faster growing prawn

The main focus of CSIRO's research is to help prawn farmers meet their commercial requirements for a prawn breed that delivers better yields. Consequently, CSIRO's selective breeding efforts have primarily been aimed at breeding a prawn that has faster growth rates and a more consistent size.

A further benefit of the breeding project has been the breeding of prawns that have greater resistance to common viruses. As part of the breeding project every potential parent prawn has a small piece of tissue snipped off for DNA fingerprinting and determining the viral load. If the prawn has an above average viral load it is judged to be less resistant to viruses and removed from the breeding project. Over time this selective breeding leads to prawn stocks that are more resistant to endemic prawn viruses.

It is important to understand that CSIRO does not provide prawn stock to prawn farmers but rather applies the breeding technologies and practices that it has developed to that farm's existing prawn stock. The key outputs of CSIRO's breeding project are:

- A detailed manual that provides prawn farmers with a standard operating procedure to help guide domestication and selective breeding projects on each prawn farm.
- A software package, including a detailed database program that allows prawn farmers to track prawn pedigree, select optimal mating, control inbreeding, and optimise selection of improved growth rates, feed conversion efficiency and tolerance to disease.
- Specialised training provided by CSIRO for prawn farm staff in new breeding practices and CSIRO's breeding project. This includes manuals, in-person instruction from CSIRO staff and other training aids.
- Ongoing analytical services. The prawn farmers regularly provide prawn breeding data to CSIRO who analyse that data and advise them on the best selection decisions to help guide each prawn farm's breeding choices.
  - Importantly, ongoing selective breeding will continue to provide benefits and those benefits are cumulative. However, if a company ceases to use the CSIRO process then its brood stock could rapidly decline in quality through poor selection, inbreeding, etc.
- Virus testing kits. The testing kit tests a piece of a prawn's body tissue to determine the viral load (a measure of the severity of viral infection). The testing serves two purposes. One is to enable early detection of viruses so that appropriate mitigation strategies can be taken to prevent the spread of disease throughout the entire prawn stock. The second is to enable more effective selective breeding for disease resistant prawns as information.

Novel prawn feed

The major output of CSIRO's research and collaboration with industry is the prawn feed additive Novacq™. The bio-active additive acts on a prawn's metabolic pathways to improve nutrient absorption from the prawn feed that Novacq™ is added to.

Novacq™ is made from agricultural waste – a world-first achievement

Novacq™ is made from what might normally be regarded as agricultural waste. Marine organisms are used to bio-convert the carbon in the agricultural waste into material that is then harvested, dried and used as a food additive for prawns. The marine microbes used in

the process are found in every pond in the world. What CSIRO have managed to do is learn how to manage that microbe and use its natural ability to convert the carbon in agricultural waste into a valuable product. The process is an entirely natural one and the only inputs are a source of carbon, sunlight and energy.

Novacq™ has been licensed to several firms

CSIRO's novel feeds research has generated two patents and an application for a third patent has been lodged. CSIRO has also established a licence for use of Novacq™ by prawn food mills. This licence comprises a standard operating procedure including instruction detailing how to produce Novacq™ and incorporate the additive into regular prawn food. Licences are regional and exclusive, meaning that only one vendor can sell Novacq™ in any given geographic region. The exception to this approach is that the licence granted to the Australian firm Ridley allows it to market and sell Novacq™ anywhere in the world.

Prawns fed Novacq™ grow 30-40 per cent faster

Novacq™ is the result of over ten years of CSIRO research. Farmed prawns that are fed the additive grow 30-40 per cent faster, are healthier and can be produced without the need for any products from wild fishery resources. This means that feed formulators/manufacturers can produce prawn feed that can be sourced from sustainable and terrestrial production.

Novacq™ is transformative, using no fish oil or meal

This is a transformative technology that removes dependency on wild-harvest fishmeal/oil for the global prawn farming industry. Greater uptake of Novacq™ will reduce demand for wild and farmed fish from the prawn industry. There is also the significant potential to increase the value of waste agricultural materials such as rice-bran.

The benefits of the additive have further strengthened Australian prawn aquaculture, which is already a global leader in sustainability and environmental management, by enabling prawn aquaculture farmers to entirely move away from wild-caught fishery products and instead use a more sustainable source of feed to meet increasing demand for food (CSIRO, 2013c).

F.3.2 Key publications

Examples of publications that flowed from the research on prawn breeding and prawn feed done by CSIRO include:

- Preston, N.P., Coman, G.J., Sellars, M.J., Cowley, J.A., Dixon, T.J., Yutao, L., Murphy, B.S. 2009. Advances in *Penaeus Monodon* breeding and genetics, pp 1-11 in Browdy, C.L. & Jory, D.E., editors. The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming, World Aquaculture 2009. The World Aquaculture Society, Baton Rouge, USA.
- Glencross, B.D., Irvin, S., Arnold, S., Blythe, Bourne, N., Preston, N.P. (2014). *Effective use of microbial biomass products to facilitate the complete replacement of fishery resources in diets for the black tiger shrimp*, Penaeus monodon. doi10.1016/j Aquaculture 2014.02.033
- Glencross, B.D., Tabrett, S.J., Irvin, S., Wade, N., Anderson, M., Blyth, D., Smith, D.M., Coman, G.E., Preston, N.P. (2013). *An analysis of the effect of diet and genotype on protein and energy utilization by the black tiger shrimp, Penaeus monodon. – why do genetically selected shrimp grow faster?* Aquaculture Nutrition 19: 128-138

F.3.3 Awards and public recognition

The quality and benefits of CSIRO's research has been recognised in the following awards:

- Australian Prawn Farmer's Association, Award for services to the prawn farming industry 2010 – Nigel Preston

- The Australian Innovation Challenge 2013, Winner of the Environment, Agriculture and Food Category: For the development of Novacq™ – the CSIRO Novacq™ team
- CSIRO Medal for Impact from Science 2014 – The Novacq™ Team (led by Dr Nigel Preston, Dr Brett Glencross and Mr Andrew Chalmers)

F.4 Status of Outcomes and Impacts

F.4.1 Nature of Outcomes and Impacts

Prawn breeding

The domestication and selective breeding of *P. monodon* has had a very significant impact on the prawn farming industry. Below we discuss how the benefits generated are distributed across different categories of beneficiaries.

The breeding project helped prawn farmers significantly increase their yields

Australian prawn farmers. The benefits have been particularly significant for this group. For example, in 2010, Gold Coast Marine, one of Australia's leading prawn farming companies were able, for the first time, to stock their whole farm with the progeny of domesticated, selectively bred broodstock. The results were that the average yields from the improved stocks was 17.5 tonnes per hectare (see Box 2) compared to the industry average for the same year of 7.8 tonnes per hectare (see APSQ, 2012).

A recent analysis of the productivity benefits of using domestic Black Tiger shrimp found that ponds stocked with domesticated *P. monodon* significantly shifted the production frontier by 39% compared to ponds stocked with wild stock (Norman-Lopez *et al*., 2014). In particular, the CSIRO prawn breeding project has helped improve the market competitiveness of *P. monodon* compared to the Pacific White shrimp (*Litopeaneus vannamei*), which has progressively replaced *P. monodon* as the most common breed in farmed prawn and shrimp production. By increasing the productivity of *P. monodon* aquaculture, prawn farmers are able to capture larger profits due to the price premium that the larger *P. monodon* commands over *L. vannamei* on the market (Norman-López *et al*., 2014).

Box F1 **Gold Coast Marine productivity gains**

The following is an excerpt from a letter from Nick Moore, General Manager of Gold Coast Marine Aquaculture Pty. Ltd. to the team leader for CSIRO's prawn breeding project.

> Some time ago I wrote to you [CSIRO's Dr. Nigel Preston] to thank you for your invaluable contribution to the monodon domestication program that allowed GCMA [Gold Coast Marine Aquaculture] to stock all 50 hectares of production ponds with domesticated stock.
>
> Last Friday we finished a season that could only be described as staggering.
>
> From those 50 hectares we produced 875 tonnes [of prawns], giving us an average of 17.5 tonnes per hectare. 14 ponds exceeded 20 tonnes per hectare with the new record now standing at 24.2. Given that this was also achieved with an FCR [feed conversion ratio, a measure of how efficient and animal is in converting feed into body mass] of 1.44 and an average weight of 37 grams, these figures are quite remarkable and far outweighed our expectations. Our results are not only records nationally, but globally too.
>
> It is our intention this coming year to aim towards the Christmas market, a target never in reach with wild progeny. The 8th generation broodstock within our maturation complex look exceptional and we are hoping to improve our ability to supply the market during historically difficult periods.
>
> Please accept not only our thanks but also our congratulations to all at CSIRO.

Source: Nick Moore, 2010, pers. comm., 26 May 2014

Overseas communities that are reliant on aquaculture. Breeding for disease resistance has been another important outcome of CSIRO's prawn breeding research as well as being the primary focus of CSIRO's work in Asia with Viet-UC, Vietnam's largest supplier of shrimp

The overseas breeding project has also produced more disease resistant prawns

seed. Asian populations of domesticated Pacific White Shrimp have historically been highly vulnerable to repeated waves of disease. The latest wave of early mortality syndrome, a bacterial disease has resulted in stock loss in the tens of billions to disease in farmed Pacific White Shrimp stocks across Asia, with some major companies recording decreased yields by as much as 50 per cent over the past year. This highlights the benefits of CSIRO's approach to selectively breeding farmed prawns for tolerance or resistance to local pathogens.

Lessons CSIRO has gained from its collaboration in Vietnam may serve as an important guide for dealing with serious disease outbreaks in Australian prawn populations in the future. Working with South-east Asian shrimp farmers also has the added benefit of monitoring and addressing disease outbreaks in the region before they have the opportunity to infect Australian prawn stocks. In the past, diseases in Asian shrimp populations have entered Australia via frozen shrimp imports, there is also potential for disease to spread via wild prawn populations.

The breeding project is generating royalties and licencing fees

CSIRO. CSIRO has also benefitted from royalties and licencing fees paid by companies licenced to utilise CSIRO's prawn domestication and breeding project. The total value of these licences and royalties will be approximately $1 million per year by 2017.

Novel prawn feed

A range of benefits have been delivered as a result of the CSIRO's research into novel prawn feed. They include: improved productivity and increased yields from prawn farms; more sustainable prawn feed; patents and royalty flows; and the creation of a market for what was previously agricultural waste. Below we discuss how benefits are distributed across different categories of beneficiaries.

Three firms have licences to produce and sell Novacq™

Prawn feed mills. Licenced prawn feed producers benefit through their ability to sell a new product with high nutrient value that eliminated feed producers' reliance on fish-meal or oil as a prawn feed additive. An important outcome of this project has been the allocation of licenses to produce and distribute Novacq™ in Australia and various countries in South-East Asia. The following three firms have to date licensed Novacq™:

- Ridley AgriProducts (sales in Australia, Indonesia, Malaysia and the Philippines)
- Viet-UC (sales in Vietnam)
- Maritech (sales in China)

The novel feed produces larger and healthier prawns

Prawn farmers. Prawn farmers benefit from access to new prawn feed that provides the capability to produce larger and healthier prawns. One on-farm trial of Novacq™ has demonstrated increased yields of 22 per cent. However, CSIRO judges this to be a conservative estimate of potential productivity gains as a result of the use of Novacq™ given much larger yield increases in research trials in controlled environment tanks (Glencross *et al*., 2013). The total productivity gains in terms of increased yields to be had when CSIRO's prawn breeding project and Novacq™ are used together are would be expected to be far higher.

Prawn farmers also have an opportunity to market their prawns as a more environmentally sustainable option compared to prawns that have been fed on fish-based feed. This may aid prawn farmers who wish to apply for established sustainability branding, which is certified and provided by organisations such as the World Wildlife Fund and Global Aquaculture. Eliminating the need to tap into wild fish stocks in order to produce prawn feed may also increase community acceptance of prawn farms on environmental grounds.

The novel prawn feed will also generate royalties

CSIRO. The CSIRO has benefited from the research by gaining potential future royalty streams from the licensing of Novacq™ as part of its novel feeds project. CSIRO is expecting royalties of roughly $250,000 in 2014, plus additional income from expansion into new geographic sales regions. By 2018, CSIRO is expecting total royalties to rise to $7.47 million, plus some additional revenue from sales in new markets.

In addition, CSIRO has strengthened its reputation for research in Australia and globally and expanded its partnerships in the global prawn and shrimp industry.

Overseas communities that are reliant on aquaculture. Use of Novacq™ and/or CSIRO's prawn breeding project may significantly increase the incomes of aquaculture communities, particularly in places where income security can be precarious, such as in Vietnam's Mekong Delta and emerging economies in other parts of Asia and in Africa.

Other beneficiaries. The community and the wild fish catching industry will benefit from a reduction in the pressure on wild fish stocks by the development and use of a prawn feed that does not use fish meal or oil. Another potential group of beneficiaries are farmers who could potentially supply what was previously regarded as agricultural waste to prawn feed manufacturers and thus realise a source of additional income.

CSIRO market and non-market impacts

Table F6 summarises the outcomes and impacts to date of CSIRO's prawn breeding and novel feeds research projects. In line with CSIRO's triple bottom line (TBL) benefit classification approach the outcomes and impacts have been categorised as environmental, social or economic.

Table F6 **Outcomes and impacts from CSIRO's prawn related research**

Outcome / Impact	Detail
Environmental impact	
Protecting existing fish stocks *Category: oceans and marine environment,* *Reach: Industry*	Decreased reliance on fish-meal and fish-oil as inputs for production in Australian Prawn Farms helping to preserve global fish stocks.
Development of a more sustainable prawn industry *Category: oceans and marine environment,* *Reach: National, Industry*	▪ Use of Novacq™ reduces feed costs in the production of farmed prawns. Development of Novacq™ decreases need to purchase fish-meal and fish-oil, thereby helping to preserve global fish stocks. Domestication of black tiger prawns also removes the need to trawl for wild broodstock for each generation of breeding. Over the long-term, these two breakthroughs promise to completely isolate black tiger prawn farming from wild fish and prawn stocks. ▪ Improved yields means that more prawns can be grown in a smaller space, potentially reducing the overall environmental footprint of black tiger prawn aquaculture.
Reduction in agricultural waste *Category: Sustainable industry development* *Reach: National*	Reduction in waste through utilisation of agricultural by-products to produce Novacq™.
Economic impact	
Improved productivity *Category: Management and productivity, New products or services,* *Reach: National*	▪ Use of Novacq™ increases Australian farmed prawn industry's production, thereby adding significant value to the industry. Proven on-farm increases in yields currently stand at 22 per cent when using high quality feeds. However, CSIRO testing suggests actual average productivity gains may prove to be much higher than this. ▪ CSIRO's black tiger prawn breeding project has led to increased production. Proven on-farm increases in black tiger prawn yields currently stand at 39 per cent compared to ponds stocked with wild prawn stocks. ▪ Use of Novacq™ increases production efficiency of farmed prawns through increased growth rates of up to 40 per cent.

Outcome / Impact	Detail
Improved competitiveness of Australian black tiger prawns *Category: Management and productivity, New products or services,* *Reach: National, Global*	▪ CSIRO's black tiger prawn breeding project has improved the competitiveness of Australian-produced prawns against imported shrimp, particularly Pacific White Shrimp produced in Asia. ▪ By increasing the productivity of black tiger prawn farming, Australian prawn farmers stand to capture a larger share of profits due to the price premium that larger, higher quality black tiger prawns command on the market.
Access to improved prawn feed *Category: New products or services,* *Reach: National, Global*	Development of Novacq™ improves the health and increases the size of black tiger prawns in particular by between 20 and 40 per cent depending on the overall quality of the diets used.
Access to virus detection kits *Category: New products or services,* *Reach: National, Global*	Virus detection kits enable early detection of diseases in prawn stocks and selective breeding for disease resistance. This has led to substantially lower loss of stock due to disease, particularly in Vietnam, where exposure of prawn stocks to disease is particularly severe.
Access to improved prawn breeds *Category: New products or services,* *Reach: National, Global*	Domesticated and selectively bred black tiger prawns are larger, have faster growth rates and are more disease resistant. CSIRO has been able to achieve similar improvements in selective breeding of White Pacific Shrimp in Vietnam, particularly in terms of improved disease resistance.
Increased employment *Category: The micro economy* *Reach: Firm*	The licencing of Novacq™ has delivered increased employment opportunities in Australia with one Australian supplier, Ridley AgriProducts, hiring an additional 7 staff for the pilot production site.
Social impact	
Access to better quality, cheaper prawns *Category: Equity and equality, Standard of living* *Reach: National*	Australian consumers will have access to competitively priced, higher quality prawns as a result of the superior size and health of farmed prawns and prawn production productivity gains as a result of CSIRO prawn breeding projects and use of Novacq™.
More reliable income streams *Category: Resilience* *Reach: National, Global*	Using prawns with improved disease resistance reduces the risk of catastrophic stock losses and subsequent loss of income. This may become particularly important for communities which are vulnerable to income loss from aquaculture, such as aquaculture and fishing communities in Vietnam's Mekong Delta.

Source: ACIL Allen Consulting; and CSIRO 2013a, 'Advancing aquaculture feed and prawn breeding', <http://www.csiro.au/Portals/About-CSIRO/What-we-do/Impact-case-studies/Aquaculture.aspx> , accessed 7 August 2014; and Norman-Lopez et al., *forthcoming*, 'Productivity benefits of using domestic Black Tiger shrimp'

F.4.2 Counterfactual

Prawn breeding

CSIRO's breeding research is 15 years ahead of others'

The domestication and selective breeding of black tiger prawns would have encountered a lengthy delay absent CSIRO's research project. Major Asian prawn producing countries including Malaysia, Vietnam and China all embarked upon research programs in an effort to domesticate *P. monodon* black tiger prawns, which are native to Asia and Oceania. However, these research programs were not successful and as a result these major Asian producers imported *L. vannamei* Pacific White Shrimp from Mexico, and made this species the foundation for Asian shrimp aquaculture. Other black tiger prawn breeding programs in Hawaii were also unsuccessful. Therefore, ACIL Allen estimates that the domestication and selective breeding of black tiger prawns would have been delayed by at least 15 years absent CSIRO's research project.

Novel prawn feed

Development of the prawn feed would have been delayed by at least 15 years in the absence of CSIRO

Interviews with CSIRO team members who worked on the Novacq™ project suggested that the additive is unlikely to have been developed in the absence of CSIRO's ability to undertake long term multidisciplinary research. ACIL Allen will assume that in the absence of CSIRO's research, the Australian prawn farming industry would have continued with their existing practices by relying on fish-meal and fish-oil as an input to their production. Furthermore they would have faced much more severe competition from cheaper imports if the new improved prawn breeds had not been developed.

As in the case of the prawn breeding, ACIL Allen estimates that development of novel prawn feed with the same characteristics and benefits as Novacq™ would have been delayed by at least 15 years in the absence of CSIRO's research project.

F.4.3 Attribution

Prawn breeding

The core research of CSIRO's black tiger prawn breeding project was undertaken by CSIRO. However, in kind support from prawn breeders was vital to the success of the project. In particular, partner prawn breeders made considerable investments in new farm infrastructure and provided the stock for CSIRO's on-farm experimentation. ACIL Allen would therefore argue that 75 per cent of the impacts of black tiger prawn domestication and selective breeding should be attributed to CSIRO, with the remaining 25 per cent of the impacts attributable to CSIRO's prawn farm partners.

Novel prawn feed

Interviews with CSIRO team members who worked on the Novacq™ project suggested that all benefits generated from the research should be attributed to CSIRO as CSIRO staff were responsible for all of the research associated with the product.

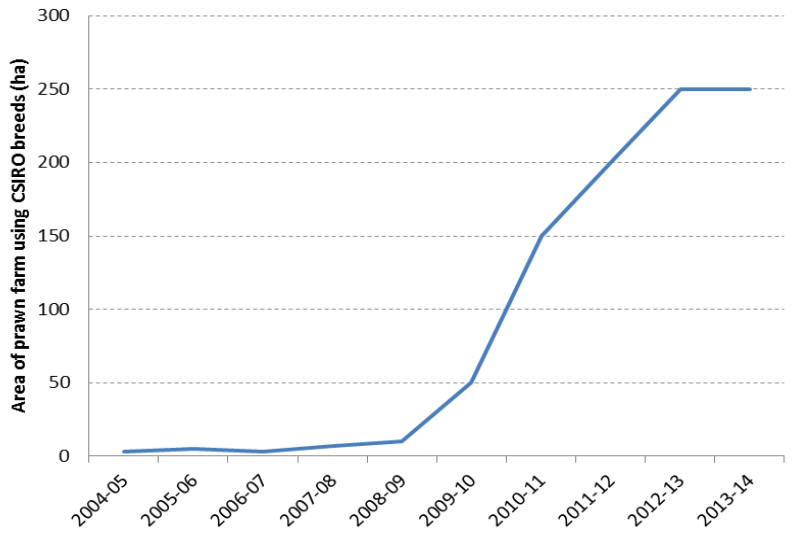
F.4.4 Adoption

Prawn breeding

Uptake of new prawn breeds has been very rapid

The uptake of new prawn breeds developed by CSIRO in Australia is shown in Figure F2. Uptake was very rapid between 2008/09 and 2012/13.

Figure F2 **Australian uptake of CSIRO prawn breeds**



Note: The total ponded area on prawn farms was 610 hectares at the end of 2010–11
Source: CSIRO and (APSQ 2012)

The reason for the current plateau of 250 ha (out of the current total of around 700 ha), is that some in the industry have been slower to make the up-front investment in the infrastructure required for on-farm domestication and selective breeding. CSIRO is currently working with the largest prawn farmer (Seafarms) to start a domestication project. This will add a further 150 ha to the area of ponds stocked with domesticated stocks by 2015-16. CSIRO are working with industry to develop the capability to supply the rest of the industry with domesticated stock by 2017-18. CSIRO expects that all Australian farms will be using domesticated stocks by 2020.

According to the director of CSIRO's prawn breeding project, Dr Nigel Preston, the area farmed is expected to double to 1,500 ha by 2024 and it is likely that CSIRO developed prawns will be used to stock all these additional ponds as well.[12]

Novel prawn feed

Marketing of Novacq™ has just begun …

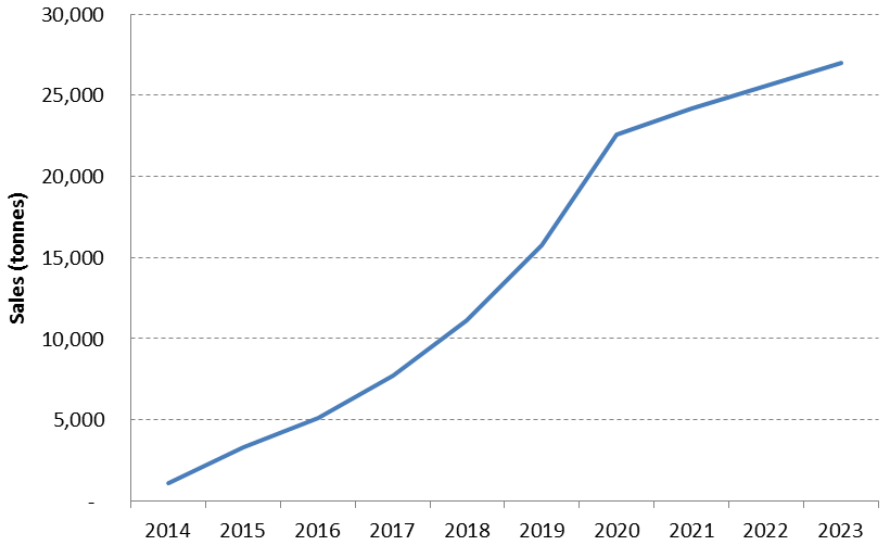
CSIRO-developed novel prawn food was only recently commercialised, so the level of uptake is relatively low at present. However, there are already three firms licensed to manufacture and sell Novacq™ which are based in Australia, China, and Vietnam. Their projected sales of Novacq™ in those countries is expected to grow rapidly, as shown in Figure F3. Each of these firms is licensed to market the prawn feed in their home country. The Australian firm is also licensed to market worldwide.

… but growth rates are projected to be substantial

Annual growth rates in sales of the CSIRO developed prawn feed in existing markets are projected to exceed 40% out to 2020.

[12] It is thought that much of the new prawn farming areas will be in Northern Australia.

Figure F3 **Projected sales of Novacq™**



Note: Sales of Novacq™ only began in 2013/14
Source: CSIRO

In addition, CSIRO is projecting that sales of Novacq™ in new or emerging markets such as Thailand and Ecuador could reach 45,000 tonnes by 2025.

Box F2 **Impact of CSIRO's media strategy on adoption rates**

Strong current and expected adoption rates of both CSIRO's domesticated black tiger prawns (and the associated breeding programme) and Novacq™ have been boosted by CSIRO's media campaign. CSIRO prepared its media messaging and engaged in concerted media outreach first in 2010, when the success of the black tiger prawn domestication and breeding project became apparent, and then in 2013/14, when Novacq™ was commercialised. Extensive media coverage of these breakthroughs was very effective in alerting the prawn industry to CSIRO's prawn aquaculture research, with the result that a number of prawn farming companies and prawn food mills to approach CSIRO to buy a licence to the breeding project or use Novacq™ in feed production.

This aided CSIRO in extending adoption of its prawn breeding project and Novacq™ into several key international markets, as well as increasing adoption rates in Australia. Recent media coverage of Novacq™ has directly led to sales and sales enquiries from new major prawn and shrimp producing markets, such as the Philippines, Indonesia, Malaysia, Ecuador, Thailand, India, Saudi Arabia, Oman, Mozambique and Madagascar.

CSIRO's media campaign has also led to new research and development partners. For example, media coverage in 2010 prompted Vietnam's Viet-UC, a company that today holds roughly 30 per cent of Vietnam's prawn production market, to approach CSIRO over a prawn breeding project for its *L. vannamei* Pacific White Shrimp stock. This was the start of several years of ongoing collaboration between CSIRO and Viet-UC.

Source: ACIL Allen; CSIRO 2013d, 'July 2013: Novacq™ prawn feed additive Media campaign associated with the industry launch and licensing agreement announcement – Evaluation Report', Canberra.

F.5 Assessment of impacts

F.5.1 Impacts to date

Economic impacts

Productivity gains will flow from CSIRO's research

Use of both Novacq™ and CSIRO's prawn domestication and breeding project delivers significant productivity gains.

Improved productivity: Latest on-farm evidence points to increased yields of at least 22 pre cent from the use of a premium prawn feed ($2.20/kg) with Novacq™ as an additive compared to prawns fed the same premium diet without Novacq™. However, on-farm and controlled environment trials using industry standard prawn feed ($1.80/kg) with or without Novacq™ have shown that prawns fed the standard feed containing Novacq™ grew 30-40 per cent faster.

On-farm evidence points to increased yields of at least 39 per cent as a result of the application of CSIRO's black tiger prawn domestication and breeding project. Finally, small scale tanks trails have demonstrated that the combined effects of selective breeding and the use of Novacq are highly synergistic (Glencross *et al*., 2013)

With the continued application of CSIRO's prawn breeding project, yields will continue to increase vis-à-vis the base case. If all of Australian prawn farms were stocked with domesticated and selectively bred black tiger prawns, CSIRO estimates that increases in yields would be 7,000 tonnes more than the current prawn farms production of roughly 5,850 tonnes. This would add approximately $120 million to the farm gate value of the industry.[13]

Efficiency and competitiveness will increase

Improved competitiveness: CSIRO's prawn breeding and novel feeds projects promise to improve production efficiencies for prawn farmers, although there will be some upfront capital expenditure associated with the prawn breeding project, due to the need for prawn farmers to invest in additional infrastructure. Domestication and selective breeding of black tiger prawns removes the need for prawn farmers to trawl wild prawns to collect broodstock for each new generation of prawns. Use of Novacq™ provides feeds that deliver faster growth rates. Farmers have the option of harvesting their crops earlier (to meet market demands when prices are highest) or to achieve larger size prawns in the same growing season and to take advantage of the higher prices paid for larger prawns.

Prawn farmers utilising Novacq™ and/or CSIRO's prawn breeding project can sell larger, healthier prawns that command a price premium on the market. At the same time, lower production costs will give prawn producers leeway to lower final selling price of their prawns, potentially taking greater market share and making Australian produced prawns more competitive with imported frozen shrimp.

In addition to economic benefits to Australia, a large part of the total economic benefits from CSIRO's prawn breeding project accrue overseas. In particular, Vietnam's prawn industry has benefitted from the partnership between CSIRO and Viet-UC, in which CSIRO has supplied the selective breeding techniques used on Australian black tiger prawns to Vietnamese Pacific White Shrimp. The collaboration with Viet-UC has resulted in faster growing prawns. Viet-UC is one of Vietnam's leading seed stock producers and anticipates significant future growth and associated benefits from using CSIRO's breeding technology.

[13] Calculation based on industry advice to CSIRO on recent farm-gate prices. Note that farm gate prices exceed $20 a kg around Christmas and Easter.

While the direct economic benefits of CSIRO's partnership with Viet-UC accrue to Vietnam, Australia also gains indirect economic benefits through this partnership. In particular, this partnership has enabled CSIRO to develop its breeding techniques specifically to combat high levels of disease in prawn stocks. The lessons gained from CSIRO's work in Vietnam will be applied to the Australian prawn industry if a wave of disease strikes Australian prawn stocks, potentially narrowing the time between the outbreak of disease and the application of effective mitigation strategies.

Employment: The commercialisation of Novacq™ has provided extra employment opportunities at Ridley AgriProducts, which is licenced to sell the feed additive. There are seven full time equivalent (FTE) staff at Ridley directly associated with the sale of Novacq™.

Environmental impacts

CSIRO's R&D has significant environmental benefits

Protecting existing wild fish stocks: The most important environmental impact of CSIRO's prawn breeding and novel feeds projects is the independence of black tiger prawn aquaculture from wild fish and prawn populations. Novacq™ provides adequate nutrition to prawns when added to quality plant-based prawn feed, so there is no need to harvest wild fish in order to add fish meal and fish oil to prawn feed.

Improved sustainability: In addition, CSIRO's black tiger prawn domestication project has removed the need for prawn farmers to harvest wild prawns in order to provide broodstock for the next generation of prawns. Moreover, increased prawn yields per hectare means a smaller environmental footprint in terms of the size of prawn farms.

Social impacts

Access to better, cheaper prawns: The development of Novacq™ and CSIRO's prawn breeding project will make larger, healthier prawns available to Australian customers at a price that is more competitive compared to alternatives, such as imported shrimp.

More reliable income streams: Greater consistency of prawn production as a result of CSIRO's breeding project – in terms of consistency of prawn sizes, yield sizes, and lower levels of stock loss due to disease – may also help to increase food security and income security for vulnerable communities overseas, such as fishing and aquaculture communities in the Mekong Delta.

F.5.2 Potential future impacts

Ongoing research will extend the gains already delivered

CSIRO is undertaking ongoing research designed to extend the gains arising from its black tiger prawn breeding and novel feeds research projects. A major focus of this ongoing research is the development of vaccines against common prawn diseases. CSIRO has been successful in injecting double stranded RNA to prevent viral infections and is currently working on developing a coating for this RNA so that it can be co-delivered in Novacq™.(Sellars *et al*., 2011) CSIRO is confident that a breakthrough on this coating technology will occur, meaning that Novacq™ will be enhanced in the future with vaccination properties.

CSIRO has incorporated an environmental management system into its prawn breeding project in order to manage the emission of waste products from prawn farms. This could have a large impact on the siting of prawns, particularly in areas that are environmentally sensitive but highly suited to prawn aquaculture, such as near the Great Barrier Reef.

F.5.3 Cost Benefit Analysis

ACIL Allen has estimated that the total accrued benefits from this project over the period will be around $882.2 million (including royalties revenues) 2004/05 to 2023/24 that is attributable to CSIRO. More information on the breakdown of that benefit is provided in the sections that follow.

Prawn breeding

The rate of return from prawn breeding is almost 250 per cent

CSIRO's prawn breeding project has delivered total benefits of $73.5 million to Australia between 2004/05 and 2013/14 compared to total input costs of $16 million over the same period. Given that 75 per cent of the impacts of CSIRO's prawn breeding project are attributable to CSIRO (see Section F.4.3) the net benefits attributable to CSIRO are approximately $39.1 million. This suggests a return of 245 per cent over total input costs for CSIRO-attributable benefits.

ACIL Allen estimates that CSIRO's prawn breeding project will accrue additional benefits equal to $452.5 million over the period 2014/15 to 2023/24 under a 5 per cent discount rate, of which 75 per cent, or $339 million, are attributable to CSIRO.

Data used for the prawn breeding cost-benefit analysis is presented in Table F7 and Table F8.

ACIL Allen has drawn on CSIRO historical data and projections of total hectares under black tiger prawn aquaculture production, combined with average yields (in terms of tonnes per hectare) for wild-caught broodstock black tiger prawns (which is the counterfactual) versus domesticated black tiger prawns subject to CSIRO's breeding project.

According to CSIRO, prawn production area using the domesticated broodstock is expected to increase from 250 ha in 2013/14 to 700 ha in 2018/19 as adoption of such broodstock increases to 100 per cent of domestic prawn production. In the following five years (from 2018/19 to 2023/24), prawn production is expected to double from 700 ha to 1,400 ha with new prawn farming areas being established in Northern Australia. CSIRO anticipates that its domesticated broodstock will be used in all the additional prawn farms.

For the cost-benefit projection out to 2023/24, ACIL Allen has assumed no increase in yield productivity for either wild or domesticated black tiger prawns after 2013/14 (the latest year for which production data is available). ACIL Allen has based projections of increasing hectares of aquaculture under black tiger prawn production based on forecasts provided by CSIRO.

ACIL Allen has used historic farm-gate prawn prices (in dollars per tonne) in inform calculations of the total value of wild and domesticated prawn production and net benefits. For projections out to 2023/24 farm-gates prices have been frozen at $17,500/tonne in 2014/15 dollars, the farm-gate price in 2013/14, which is the latest year for which data is available.

Table F7 **Prawn breeding benefits**

Year	Area under production (domesticated)	Average yield wild	**Average yield domesticated**	Price	Value – wild	Value – domesticated	Increased production costs	Net benefit
	(ha)	(t/ha)	(t/ha)	($/t)	($)	($)	($)	($)
2004-05	3	4	5.5	15,000	180,000	247,500	32,130	**35,370**
2005-06	5	4	5.6	16,000	320,000	448,000	57,120	**70,880**
2006-07	3	4.2	5.9	16,000	201,600	283,200	36,414	**45,186**
2007-08	7	5.1	7.1	16,000	571,200	795,200	99,960	**124,040**
2008-09	10	6.2	10.5	17,000	1,054,000	1,785,000	307,020	**423,980**
2009-10	50	7.8	17.5	17,500	6,825,000	15,312,500	3,462,900	**5,024,600**
2010-11	150	7.8	15.5	17,500	20,475,000	40,687,500	8,246,700	**11,965,800**
2011-12	200	7.8	15.5	17,500	27,300,000	54,250,000	10,995,600	**15,954,400**
2012-13	250	7.8	15.5	17,500	34,125,000	67,812,500	13,744,500	**19,943,000**
2013-14	250	7.8	15.5	17,500	34,125,000	67,812,500	13,744,500	**19,943,000**
2014-15	307	7.8	15.5	17,500	41,928,012	83,318,484	16,887,313	**24,503,160**
2015-16	377	7.8	15.5	17,500	51,515,257	102,370,062	20,748,761	**30,106,045**
2016-17	464	7.8	15.5	17,500	63,294,719	125,777,968	25,493,165	**36,990,083**
2017-18	570	7.8	15.5	17,500	77,767,670	154,538,318	31,322,424	**45,448,224**
2018-19	700	7.8	15.5	17,500	95,550,000	189,875,000	38,484,600	**55,840,400**
2019-20	804	7.8	15.5	17,500	109,758,128	218,109,100	44,207,197	**64,143,776**
2020-21	924	7.8	15.5	17,500	126,078,981	250,541,565	50,780,734	**73,681,850**
2021-22	1061	7.8	15.5	17,500	144,826,718	287,796,683	58,331,746	**84,638,219**
2022/23	1,219	7.8	15.5	17,500	166,362,213	330,591,576	67,005,580	**97,223,783**
2023/24	1,400	7.8	15.5	17,500	191,100,000	379,750,000	76,969,200	**111,680,800**

Source: ACIL Allen Consulting, CSIRO

Total costs for the prawn breeding project (comprising CSIRO support, external cash co-invested support and external in-kind support) are equal to $16 million, as outlined in Table F8.

Table F8 **Prawn breeding costs**

Year	CSIRO support	External cash co-invested support	External in-kind support
	$ million	$ million	$ million
2004-05	1.20	.26	.09
2005-06	1.23	.25	.08
2006-07	1.22	.20	.07
2007-08	1.23	.35	.12
2008-09	1.25	.27	.09
2009-10	1.00	.16	.05
2010-11	1.20	.24	.08
2011-12	1.30	.37	.12
2012-13	1.20	.54	.18
2013-14	1.10	.40	.13
Total	**11.93**	**3.04**	**1.03**

Source: CSIRO

Prawn breeding + novel prawn feed

Novacq™ will deliver significant future benefits …

Novacq™ has not yet delivered additional value because it has only very recently been released onto the market. This means that total benefits from the combination of prawn breeding and novel prawn feeds (Novacq™) are between 2004/5 and 2013/14 are $73.5 million, all of which comes from prawn breeding. Given that 75 per cent of the impacts of CSIRO's prawn breeding project are attributable to CSIRO, the total benefits net of input costs that attributable to CSIRO are approximately $55.1 million. When the total cost of CSIRO's prawn breeding and novel feeds project are taken into account ($16 million plus $12.3 million), net benefits fall to $26.8 million in the period 2004/5 to 2013/14.

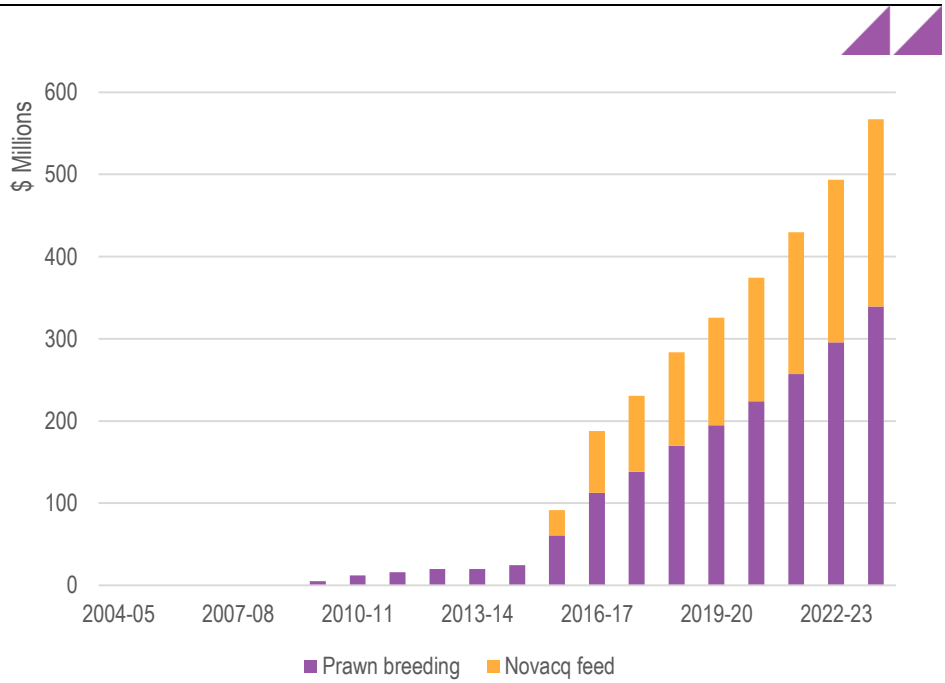
Novacq™ is expected to produce significant benefits in the 2014/15 to 2023/24 period. ACIL Allen forecasts suggest that incremental benefits from the use of novel prawn feed will be equal to $368.3 million over and above benefits gained from the use of CSIRO's breeding project over the same period, using a 5 per cent discount rate. In addition, CSIRO will earn roughly $101 million in royalties from the domestic and overseas sale of Novacq™.

… including around $100 million in royalties

Data underlying the prawn breeding cost-benefit analysis is presented in Tables F7 and F8, below.

For this analysis, area under black tiger prawn aquaculture production, wild broodstock average yield (in tonnes per hectare), farm-gate prices and total value of wild prawn production are consistent with Table F7, as these factors are not necessarily impacted by the use of Novacq™.

Figure F4 **Net benefits of prawn breeding versus prawn breeding + novel prawn feed**



Source: ACIL Allen Consulting; CSIRO

From 2015/16 to the end of the forecast period (2023/24), average yield of domesticated prawns (tonnes per hectare) increases based on information supplied to ACIL Allen by CSIRO. In particular, yields with Novacq™ (in conjunction with the use of domesticated broodstock) are expected to reach 22 t/ha. It is expected that full adoption of Novacq™ in all Australian prawn farms will be achieved by 2016-17. The average yield is therefore assumed to be 18.8 t/ha in 2014-15, 23.4 t/ha in 2025-16 and 22.0 t/ha from 2016/17 onwards.

According to CSIRO, Novacq™ will have a negligible impact on input costs per tonne which include the cost of feed, utilities and labour. It is assumed that input costs per tonne in real terms remain at $7,140 per tonne in 2014/15 dollars. Of course, total input costs will be higher than in the counterfactual because of the expected increase in yield (and hence production).

In Table F9, data on wild prawn yield (tonnes/ha) and farm-gate prices have been omitted, in order to ensure that the table is readable. This information, which has fed into the total benefits calculation in the final column, can be found in Table F7. The projected royalties

from Novacq™ shown in Table F9 are the combined royalties from both Australian and international licensees. The bulk of the royalties are expected to be from the latter.

Table F9 **Benefits of prawn breeding and novel feed**

Year	Area under production domesticated	**Average yield domesticated**	Value – wild	Value – domesticated	Increased production costs	Net benefit	Royalties from Novacq™	Total benefits
	ha	t/ha	$	$	$	$	$	$
2004-05	3	5.5	180,000	247,500	32,130	35,370	0	**35,370**
2005-06	5	5.6	320,000	448,000	57,120	70,880	0	**70,880**
2006-07	3	5.9	201,600	283,200	36,414	45,186	0	**45,186**
2007-08	7	7.1	571,200	795,200	99,960	124,040	0	**124,040**
2008-09	10	10.5	1,054,000	1,785,000	307,020	423,980	0	**423,980**
2009-10	50	17.5	6,825,000	15,312,500	3,462,900	5,024,600	0	**5,024,600**
2010-11	150	15.5	20,475,000	40,687,500	8,246,700	11,965,800	0	**11,965,800**
2011-12	200	15.5	27,300,000	54,250,000	10,995,600	15,954,400	0	**15,954,400**
2012-13	250	15.5	34,125,000	67,812,500	13,744,500	19,943,000	0	**19,943,000**
2013-14	250	15.5	34,125,000	67,812,500	13,744,500	19,943,000	0	**19,943,000**
2014-15	307	15.5	41,928,012	83,318,484	16,887,313	24,503,160	714,200	**25,217,360**
2015-16	377	18.8	51,515,257	123,834,753	29,506,354	42,813,141	1,151,800	**43,964,941**
2016-17	464	22.0	63,294,719	178,523,568	47,013,370	68,215,478	3,080,200	**71,295,678**
2017-18	570	22.0	77,767,670	219,344,709	57,763,432	83,813,607	6,011,700	**89,825,307**
2018-19	700	22.0	95,550,000	269,500,000	70,971,600	102,978,400	8,520,940	**111,499,340**
2019-20	804	22.0	109,758,128	309,574,207	81,524,960	118,291,119	11,844,622	**130,135,741**
2020-21	924	22.0	126,078,981	355,607,382	93,647,588	135,880,813	14,959,091	**150,839,905**
2021-22	1,061	22.0	144,826,718	408,485,615	107,572,830	156,086,067	17,458,069	**173,544,135**
2022-23	1,219	22.0	166,362,213	469,226,754	123,568,733	179,295,808	18,257,086	**197,552,895**
2023-24	1,400	22.0	191,100,000	539,000,000	141,943,200	205,956,800	19,225,829	**225,182,629**

Source: ACIL Allen Consulting; CSIRO

Total input costs for conducting the novel prawn feed project were $12.3 million, as shown in Table F10.

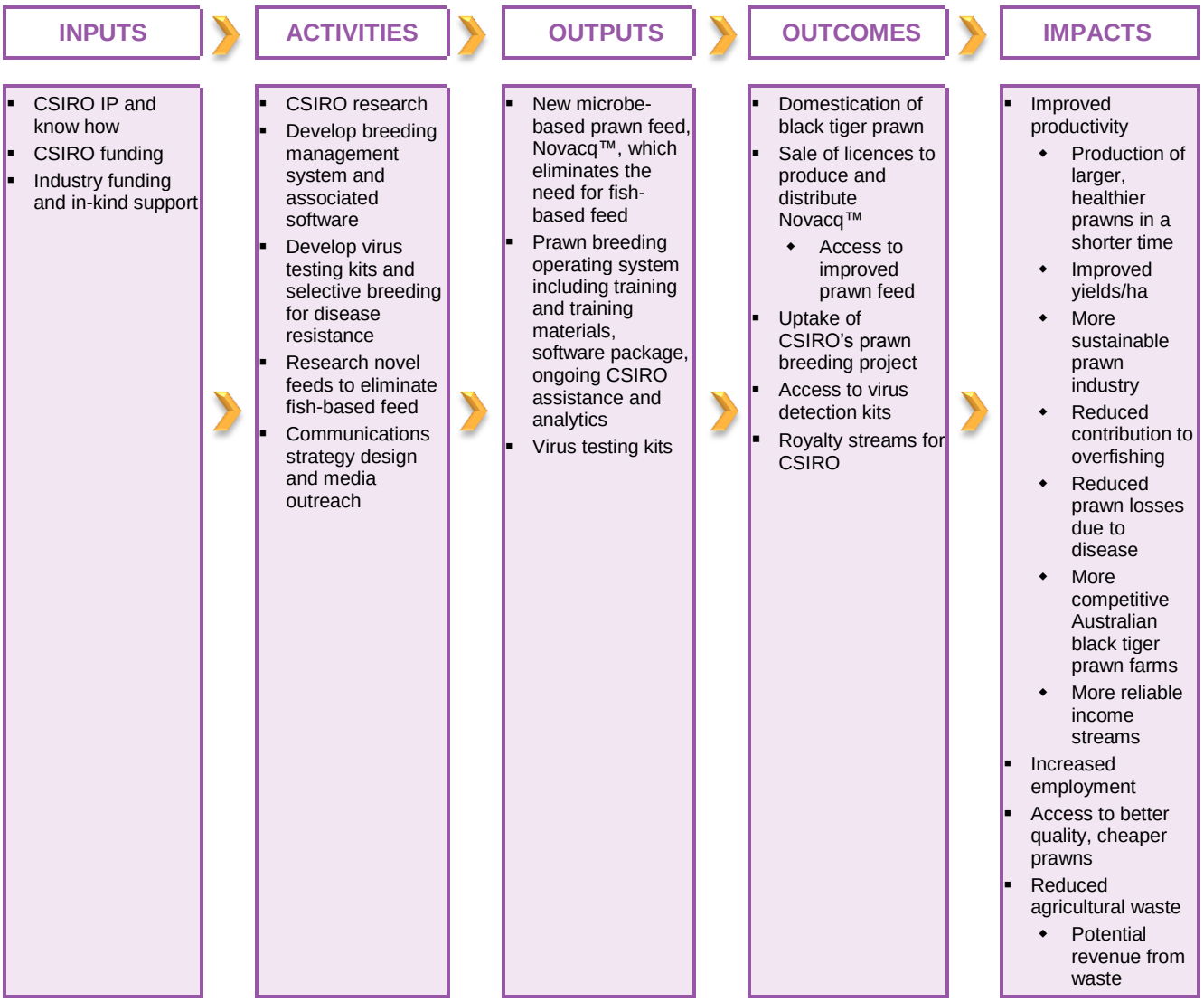
Table F10 **Novel prawn feeds costs**

Year	CSIRO support	External cash co-invested support	External in-kind support
	$ million	$ million	$ million
2004-05	0.85	0	0
2005-06	1.20	0	0
2006-07	1.35	0	0
2007-08	1.27	.2	.1
2008-09	1.40	.15	.07
2009-10	1.01	0	0
2010-11	0.80	0	0
2011-12	0.83	.4	.2
2012-13	0.99	.26	.13
2013-14	0.39	.50	.18
Total	**10.10**	**1.51**	**.69**

Source: CSIRO

Figure F5 presents CSIRO's impact evaluation framework diagram for its work on prawn breeding and feed.

Figure F5 **Aquaculture feed and prawn breeding – Impact evaluation diagram**



Source: ACIL Allen Consulting

F.6 References

ABARES 2010, *Australian fisheries statistics 2009*, <http://www.daff.gov.au/ABARES/pages/publications/display.aspx?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pe_abares99000008_14a.xml> , accessed 21 August 2014

ABARES 2013, *Australian fisheries statistics 2013*, <http://www.daff.gov.au/ABARES/pages/publications/display.aspx?url=http://143.188.17.20/anrdl/DAFFService/display.php?fid=pb_afstad9aamd0032012_11a.xml>, accessed 21 August 2014

APSQ 2012, *Aquaculture Production Survey Queensland 2010–11*, Max Wingfield, Department of Agriculture, Fisheries and Forestry, October 2012

CSIRO 2013, *Food Futures Flagship 2012-13 Annual Report*, 2013

CSIRO 2013a, *Advancing aquaculture feed and prawn breeding*, <http://www.csiro.au/Portals/About-CSIRO/What-we-do/Impact-case-studies/Aquaculture.aspx>, accessed 7 August 2014.

CSIRO 2013b, *Prawn farming: towards a sustainable and profitable future*, <http://www.csiro.au/Organisation-Structure/Flagships/Food-Futures-Flagship/Breed-Engineering-Theme/Aquaculture--Prawn-farming-Towards-a-sustainable-and-profitable-future.aspx>, accessed 7 August 2014.

CSIRO 2013c, *Perfect food for perfect prawns*, <http://www.csiro.au/Portals/Media/Perfect-food-for-perfect-prawns.aspx>, accessed 7 August 2014.

CSIRO 2013d, 'July 2013: *Novacq™ prawn feed additive Media campaign associated with the industry launch and licensing agreement announcement – Evaluation Report*, Canberra.

CSIRO 2014a, *Food Futures Flagship Performance Report* (extract), 2014.

FAO 2009, *Global Study of Shrimp Fisheries*, <ftp://ftp.fao.org/docrep/fao/011/i0300e/i0300e.pdf>, accessed 22 August 2014

FAO 2014, '*World Review of Fisheries and Aquaculture*', <http://www.fao.org/3/a-i3720e/index.html>, accessed 22 August 2014

Glencross, B.D., Irvin, S., Arnold, S., Blythe, Bourne, N., Preston, N.P. (2014). *Effective use of microbial biomass products to facilitate the complete replacement of fishery resources in diets for the black tiger shrimp, Penaeus monodon*. doi10.1016/j Aquaculture 2014.02.033

Glencross, B.D., Tabrett, S.J., Irvin, S., Wade, N., Anderson, M., Blyth, D., Smith, D.M., Coman, G.E., Preston, N.P. (2013). *An analysis of the effect of diet and genotype on protein and energy utilization by the black tiger shrimp, Penaeus monodon – why do genetically selected shrimp grow faster?* Aquaculture Nutrition 19: 128-138

Moore N, 2010, personal communication by letter with Nigel Preston of CSIRO, 26 May

Norman-López 2013, Ana Norman-López, Melony Sellars, Sean Pascoe, Greg Coman, Brian Murphy, Nick Moore, Nigel Preston, *Productivity benefits of using domestic Black Tiger shrimp* (unpublished draft), November 2013

Preston, N.P., Coman, G.J., Sellars, M.J., Cowley, J.A., Dixon, T.J., Yutao, L., Murphy, B.S. 2009. Advances in Penaeus Monodon breeding and genetics, pp 1-11 in Browdy, C.L. & Jory, D.E., editors. *The Rising Tide, Proceedings of the Special Session on Sustainable Shrimp Farming*, World Aquaculture 2009. The World Aquaculture Society, Baton Rouge, USA.

Sellars MJ, Rao M, Arnold SJ, Wade NM, Cowley JA. *Penaeus monodon is protected against gill-associated virus by muscle injection but not oral delivery of bacterially expressed dsRNAs* Dis Aquat Organ. 2011 May 24;95(1):19-30. doi: 10.3354/dao02343.