Replacing Fishmeal in Aquaculture Diets

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TABLE OF CONTENTS

LIST OF TABLES

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EXECUTIVE SUMMARY

Final Report on ACIAR Project No. PN 9207

Project:	Replacing Fishmeal in Aquaculture Diets
Commissioned Organisation:	NSW Fisheries Port Stephens Fisheries Centre Private Bag 1 Nelson Bay NSW 2315 Australia
Collaborating Institutions*:	NSW Agriculture Queensland Department Primary Industries CSIRO Marine Research, Cleveland CSIRO Animal Production, Sydney CSIRO Food Science & Technology, Sydney University of NSW Queensland University of Technology University of Tasmania, Launceston

* Collaborating agencies under a collaborative Replacement of Fishmeal in Aquaculture Diets Sub-program funded by the Australian Fisheries Research and Development Corporation (FRDC). These agencies were not funded by this ACIAR project although the overall objectives of the ACIAR and FRDC Projects were complementary.

Project Leaders:

(i)	Australia:	Dr Geoff Allan
(ii)	Thailand:	Dr Wimol Jantrarotai

Date of Commencement:	October 1993
Date of Completion:	May 1999

Aims of Projects:

1. To thoroughly review available ingredients which have the potential singly, or in combination with other ingredients, to replace fishmeal or `trash fish' in aquaculture diets.
2. To determine the digestibility of alternative protein sources to fishmeal.
3. To formulate, using digestibility data, nutritionally balanced diets using alternative ingredients to fishmeal or `trash fish' and to compare performance of fish on these diets with that of fish on fishmeal diets.
4. Determine optimum protein requirements and the potential for `sparing' protein using fat or carbohydrate.
5. To determine the potential use of commercially available, synthetic amino acid supplements in fish diets.

This project was reviewed in 1996/97 by Drs Williams and Wee (Australia) and Professor Wiang (Thailand). The reviewers recommended the project be continued in both countries with the following extra objectives (expanding on Objectives 1 and 2 and adding two new objectives – 6 and 7):

1.1. Expand databases on Thai ingredient availability and cost.

1.2 Analyse ingredients for energy and amino acids (and proximates if this information is missing for some ingredients).

2.1. Measure digestibility of more ingredients with hybrid catfish.

6. Implement an effective and widespread extension program to ensure results benefit farmers (particularly in Thailand).

7. Undertake research in Australia to improve feed management for silver perch.

Description of Work

Tables 1 and 2 give a full description of work carried out and conclusions reached in Australia and Thailand.

Results, Conclusions and Assessments

A summary of the major conclusions for each objective for both countries is presented in Tables 1 and 2. The research in both countries has been very effective. In Australia, research under this ACIAR project and the complementary FRDC projects provided the base for the development of diets for silver perch (*Bidyanus bidyanus*). This species is new to aquaculture and this is the first major nutritional study conducted. Most commercial diets now in use were formulated and evaluated by the project leader and contain only 5% fishmeal. Major nutritional requirements for silver perch are now known and the potential for a wide range of available ingredients thoroughly evaluated. Commercial feed manufacturers now have the information to formulate low-cost, effective diets using Australian agricultural ingredients, with no fishmeal.

Development of low-cost, effective diets has been of critical importance to the development of the silver perch farming industry in Australia. This industry is expanding rapidly. Nutritional research by NSW Fisheries (including that under this ACIAR project and the complementary FRDC project) has led to the development of diets based on Australian agricultural ingredients such as meatmeal, poultry offal meal, lupins, field peas, canola and wheat with no need for expensive imported ingredients such as fishmeal. These diets have been adopted by commercial feed manufacturers (some have retained 5% fishmeal) and the cost of feeding silver perch has now been reduced to around $1.00/kg of fish. The overall cost of production on efficient farms is below $5.00/kg.

Annual production in NSW doubled each year from 2.6 tonnes in 1992/93, to 81 tonnes in 1996/97, and around 250 tonnes in 1997/98. An additional 30-50 t are farmed annually in Queensland. There are around 400 ha of ponds completed or under construction in NSW and Queensland. Currently there is a low proportion of permit holders producing fish, and a small area of ponds under culture. Most operational farms, and consequently the industry as a whole, are inefficient and not producing any where near their potential. Successful nutrition research and subsequent commercial diet development combined with the production capacity of silver perch in ponds and the large number of licenced, but unproductive or inefficient farms, provide the basis for a dramatic increase in production over the next 5-10 years. If the industry realises this potential, it will become one of Australia's largest fisheries.

In Thailand, research under the ACIAR project has provided a sound base for diet development from the hybrid walking catfish (*Clarias macrocephalus* x *C. gariepinus*). In similarity with the situation with silver perch, this is the first major nutrition study conducted with the hybrid walking catfish. It has become clear that the hybrid walking catfish has somewhat different nutritional requirements compared with either parent species.

Partly as a result of this project, hybrid walking catfish culture has expanded enormously in Thailand. Estimates of catfish production in Thailand when the project commenced were about 50 000 t/year. Recent figures suggest current production now exceeds 60-70 000 t/yr. The project has contributed to this expansion by making technology for nutritionally adequate farm-made diets widely available. This has been achieved through a focused, comprehensive extension program involving extension articles and booklets (over 12 000 copies of one of these have been printed), video presentations (screened on national television) and farmer-orientated workshops (over 220 people have received comprehensive training in farm-made feeds).

There are a number of possible future directions to the work. These include:

- Continuing to expand extension for farmers and feed manufacturers involved in both silver perch and catfish industries.
- Determining requirements for expensive nutrients not determined during the present study. Particular focus is warranted on polluting nutrients such as phosphorus and expensive vitamins such as biotin and inositol.
- Expand evaluation of new ingredients in both countries.

In both countries, this project has facilitated the development of rigorous, effective nutrition research teams and well equipped facilities for laboratory-scale and commercial-scale research.

Especially for Thailand, this is a very important achievement. Sing Buri, the Department of Fisheries station where experiments have been conducted, is now recognised as a nutrition "Centre of Excellence" within Thailand. Unfortunately, much of the other research on diet development throughout south-east Asia has lacked rigour and, more importantly, lacked effective transfer to commercial farmers. One strong recommendation is the involvement of the Thailand nutrition research team to develop nutrition research capacity in neighbouring countries and to train researchers and government employees to transfer results and technology to low-income fish farmers.

Publications

Publications emanating from this project are listed in Tables 1 and 2.

Follow-up

Australia

Research on silver perch diet development has continued (1996-1999) under the new Fisheries Research and Development Corporation Sub-Program on Aquaculture Diet Development (this Sub-Program is led by Dr Geoff Allan). This research has included:

1. Ingredient evaluation – focus on new ingredients, measuring utilisation of nutrients from most promising ingredients and understanding and improving carbohydrate utilisation.

2. Nutritional requirements – focus on defining interactive requirements for linolenic and linoleic series fatty acids and on determining optimum digestible protein requirements for diets with two additional digestible energy contents (optimum digestible protein contents for diets with 14-15 MJ/kg DF was determined in the current study).

3. Improving feeding strategies and evaluating commercially relevant diets formulated using results from the current study in large ponds with fish grown to market size.

Future nutrition research activities planned by NSW Fisheries scientists include continued coordination of nutrition research within Australia and rapid development of diets for Australian snapper. Snapper are arguably the next species poised for large-scale commercial aquaculture in Australia. Commercial farms have started in Western Australia, South Australia and NSW. There are commercial hatcheries in these three states plus Victoria. Results from this project, including the development of effective methods, should allow rapid development of commercial diets.

Thailand

In Thailand, research will continue on hybrid walking catfish diet development and extension activities for farm-made feeds will also continue. All fisheries stations (in all 56 provinces) will receive written extension materials plus copies of the explanatory video on nutrition and farm-made feeds.

Unfortunately, due to budget limitations most of the technicians employed by the ACIAR project will be terminated. At best, one experiment per year will be possible using casual, untrained technical help. Further hands-on training of farmers will not be possible. A further project to build on the considerable success of this project in Thailand is warranted. Using existing staff and facilities to train nutrition research in other less developed countries in the region would be a very cost-effective way to capitalise on project benefits.

The maintenance of Sing Buri as a nutrition research and extension centre is recommended. Groups of researchers from other countries in the region could come to Sing Buri (some accommodation is available on-site) for training on improved nutrition research techniques and, importantly, effective extension programs. Limited expenditure in Australia could provide research resource material and staff (this could possibly be incorporated within the FRDC Sub-Program on Aquaculture Diet Development).

Table 1. Summary of Major Conclusions in Australia (All papers collected as Appendix 1)

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
1	The use of Australian oilseeds and grain legumes in aquaculture diets	Early digestibility results for some oilseeds and grain legumes for silver perch.	Allan, G.L., Rowland, S.J., 1994. The use of Australian oilseeds and grain legumes in aquaculture diets. In: Chou, L.M. et al (eds.) The Third Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines, pp. 667-669.	1, 2
2	Evaluation of meat meal as a replacement for fishmeal in diets for the omnivorous, freshwater silver perch, *Bidyanus bidyanus*	Digestibility of four different meat meals included at 2 different contents described. Digestibility better for meat meals with more protein and less ash. Growth results also presented for separate experiment.	Allan, G.L., Stone, D.A., Frances, J., Parkinson, S.A., 1996. Evaluation of meat meal as a replacement for fishmeal in diets for the omnivorous, freshwater silver perch, *Bidyanus bidyanus*. World Aquaculture Society '96. Bangkok, Thailand, 29 January to 2 February, 1996.	1, 2, 3, 5
3	Evaluation of four grain legumes in diets for silver perch (*Bidyanus bidyanus*)	Summary of experiment to determine apparent digestibility coefficients for field peas, faba beans, chick peas and vetch whole or dehulled (field peas and faba beans protein concentrates were also evaluated). Dehulling improves digestibility for some but not all ingredients.	Booth, M., Allan, G.L., 1997. Evaluation of four grain legumes in diets for silver perch (*Bidyanus bidyanus*). Proc. Nutr. Soc. Aust., 21st Annual Scientific Meeting, Brisbane, Queensland 30 November to 2 December 1997. Vol. 21:66.	1, 2
4	Digestibility of lupins by Australian silver perch, *Bidyanus bidyanus*	Summary of experiment which measured digestibility of two species of lupins included in diets at each of 2 concentrations as either whole or dehulled product. Protein digestibility was very high. Dry matter and energy digestibility was best for the dehulled product.	Allan, G.L., Evans, A., Gleeson, V., Stone, D.A.J., 1998. Digestibility of lupins by Australian silver perch, *Bidyanus bidyanus.* World Aquaculture Society Annual Conference, Las Vegas, 15-19 February 1998.	1, 2
5	Digestibility of wheat starch for Australian silver perch, *Bidyanus bidyanus*	Summary of results of experiment which measured digestibility of diets containing either 30 or 60% starch which was raw (0%), 25, 50 or 80% gelatinised. Starch is relatively well digested by silver perch and is improved with gelatinisation.	Stone, D.A.J., Allan, G.L., Anderson, A.J., 1998. Digestibility of wheat starch for Australian silver perch, *Bidyanus bidyanus.* World Aquaculture Society Annual Conference, Las Vegas, 15-19 February 1998.	1, 2
6	Nutrient digestibility for juvenile silver perch (*Bidyanus bidyanus*): development of methods	Experiment to develop and validate methods, measure digestibility of ingredients in diets for silver perch are described. Collection of faeces over 18 h by settlement is a suitable method and assumptions of additivity of digestibility coefficients for a number of ingredients was demonstrated.	Allan, G.L., Rowland, S.J., Parkinson, S., Stone, D.A.J., Jantrarotai, W., 1999. Nutrient digestibility for juvenile silver perch (*Bidyanus bidyanus*) (Mitchell): development of methods. Aquaculture 170, 131-145.	2
7	Alternative protein sources to fishmeal in aquafeeds: plant proteins	Review of global aquafeed requirements and potential for plant proteins to allow continual expansion of aquafeed production and and consequently aquaculture production. Constraints and possible methods of overcoming these constraints described.	Allan, G.L., Booth, M., Stone D., Williams, K., Smith, D., 2000. Alternative protein sources to fishmeal in aquafeeds: plant proteins. International Aqua Feed. Directory and Buyer's Guide 2000.	1

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
8	Replacement of fish meal in diets for Australian silver perch: digestibility of alternative ingredients	Data listing digestibility coefficients for DM, protein, energy and individual amino acids for 29 ingredients. (Scientific paper).	Allan, G.L., Parkinson, S., Booth, M.A., Stone, D.A.J., Rowland, S.J., Frances, J., Warner-Smith, R., 2000. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus*: I. Digestibility of alternative ingredients. Aquaculture 186, 293-310.	1, 2
9	Replacement of fish meal in diets for silver perch. VI. effects of increasing poultry offal meal and feather meal content on growth and body composition	Scientific paper.	Allan, G.L., Frances, J., Booth, M., Warner-Smith, R., 2000. Replacement of fish meal in diets for silver perch. VI. effects of increasing poultry offal meal and feather meal content on growth and body composition. In preparation. 1-24	3
10	Replacement of fish meal in diets for silver perch: II. digestibility of lupins	Scientific paper.	Allan, G.L., Gleeson, V., Evans, A., Stone, D., 2000. Replacement of fish meal in diets for silver perch: II. digestibility of lupins. Aquaculture (in press). 1-27	2
11	Recent developments in the use of rendered products in aquafeeds	Update for Australian Meat Renderers Association Conference of new research (since Williams et al. 1997 review) using meat meal in diets for silver perch, barramundi and prawns. Data showing meat/wheat silver perch diets (0% fishmeal) are as good as earlier diets and produce fish that taste better.	Allan, G.L., Williams, K.C., Smith, D.M., Barlow, C.G., 2000. Recent developments in the use of rendered products in aquafeeds. In: Fifth International Symposium: World Rendering Beyond 2000: Tools, techniques and the environment. 21-23 July 1999, Surfers Paradise. Australian Renderers' Association, Sydney, Australia. pp. 67-76.	1, 2, 3, 5
12	Replacement of fish meal in diets for Australian silver perch: digestibility and growth using meat meal products	Scientific paper describing in detail digestibility and growth studies with meat meal products.	Stone, D.A.J., Allan, G.L., Parkinson, S., Rowland, S.J., 2000. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus* III. Digestibility and growth using meat meal products. Aquaculture 186, 311-326.	2, 3, 5
13	Estimating optimum lysine requirements of silver perch (*Bidyanus bidyanus*)	Summary of experiment to estimate optimum requirements for lysine and protein intake.	Allan, G.L., Johnson, R.J., Frances, J., Stone, D.A.J., 1997. Estimating optimum lysine requirements of silver perch (*Bidyanus bidyanus*). Proc. Nutr. Soc. Aust., 21st Annual Scientific Meeting, Brisbane, Queensland 30 November to 2 December 1997. Vol. 21:67.	4
14	Tissue lipid relationships in silver perch fingerlings fed different diets.	Summary of results of tissue lipid concentration in fish fed diets with different lipids. Fat intake influences tissue lipd and fatty acid profile.	Hunter, B.J., Allan, G.L., Roberts, D.C.K., 1997. Tissue lipid relationships in silver perch fingerlings fed different diets. Proc. Nutr. Soc. Aust., 21st Annual Scientific Meeting, Brisbane, Queensland 30 November to 2 December 1997. Vol. 21:62	3
15	Digestibility and utilisation of carbohydrate by Australian silver perch, *Bidyanus bidyanus*	Summary of results which determined digestibility of wheat starch breakdown products glucose, dextrin or maltose. Pea starch digestibility was also measured. High digestibility of starch confirmed and digestibility improves with increasing processing.	Stone, D.A.J., Allan, G.L., Anderson, A.J., 1998. Digestibility and utilisation of carbohydrate by Australian silver perch, *Bidyanus bidyanus*. World Aquaculture Society Annual Conference, Las Vegas, 15-19 February 1998.	2, 3
16	The effects of cooking on the digestibility of a practical diet containing starch products fed to juvenile silver perch (*Bidyanus bidyanus*)	Summary of experiment which measured effects of cooking on digestibility of diets containing different types of starch (wheat, potato and maize) which was raw or cooled. Wheat starch was most digestible followed by maize then potato.	Stone, D.A.J., Allan, G.L., 1997. The effects of cooking on the digestibility of a practical diet containing starch products fed to juvenile silver perch (*Bidyanus bidyanus*). Proc. Nutr. Soc. Aust., 21st Annual Scientific Meeting, Brisbane, Queensland 30 November to 2 December 1997. Vol. 21:65.	2

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
17	Effects of grinding, steam conditioning and extrusion of a practical diet on digestibility and weight gain of silver perch	Scientific data describing effects of grinding, steam conditioning and extrusion on digestibility and growth. Results show that grinding below between 710 and 1000 µm was unnecessary but that steam conditioning was of benefit.	Booth, M.A., Allan, G.L., Warner-Smith, 2000. Effects of grinding, steam conditioning and extrusion of a practical diet on digestibility and weight gain of silver perch, *Bidyanus bidyanus.* Aquaculture 182, 287-299.	2, 3
18	Least-cost formulation and evaluation of low fishmeal diets for Australian silver perch	Summary of results for experiment to compare low-fishmeal diets (5% or 10% fishmeal); 37 or 22% meat meal and 17 or 41% legumes) with fish/soy based reference diets. Fish performance and ingredient cost was much lower for 5% fishmeal diet.	Allan, G.L., Rowland, S.R., Mifsud, C., Stone, D.A.J., 1998. Least-cost formulation and evaluation of low fishmeal diets for Australian silver perch. World Aquaculture Society Annual Conference, Las Vegas, 15-19 February 1998.	3
19	Replacement of fish meal in diets for Australian silver perch: least-cost formulation of practical diets	Scientific paper describing pond validation experiment of silver perch grown to market size using 5% fishmeal diets and taste panel studies confirming fish taste is unaffected by replacing fishmeal with meat and legumes (providing fish oil is supplied in the diet).	Allan, G.L., Rowland, S.J., Mifsud, C., Glendenning, D., Stone, S.A.J., Ford, A., 2000. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus* V. Least-cost formulation of practical diets. Aquaculture 186, 327-340.	3
20	No fishmeal needed for new high performance silver perch diets	Latest non-technical article describing positive results with 0% fishmeal diets (meat and wheat based) for silver perch for fish grown to market size in earthen ponds. Taste panel studies show that the 0% fishmeal diet actually tasted better than earlier diets and that ingredient costs had been halved. This latest and best diet was formulated to meet nutritional specifications (i.e. lower digestible protein and lysine contents) determined using earlier research and information on ingredient digestibility and utilisation and optimum processing conditions.	Allan, G., Stone, D., Booth, M., Rowland, S., 2000. No fishmeal needed for new high performance silver perch diets. NSW Fisheries Magazine (Summer), 44-45.	3
21	Fishmeal replacement using grains: present and future	Review of the use of grains in aquafeeds – evaluation, constraints, results. Coordinated research described.	Allan, G.L., 1995. Fishmeal replacement using grains: present and future. Paper presented at the GRDC Workshop – The use of agricultural grains and legumes in aquaculture feeds, 29 May 1995. SARDI, pp. 1-14.	1, 2, 3, 5
22	Development of artificial diets for silver perch	Early review of information available on nutrient requirements and ingredient evaluation for silver perch. Contains recommended feeding strategies.	Allan, G.L., 1995. Silver perch culture. In: Rowland, S.J., Bryant, C. (eds.) Proceedings of silver perch aquaculture workshops, Grafton and Narrandera, April 1994. Austrasia Aquaculture for NSW Fisheries, pp. 77-87.	3, 4, 7
23	Potential for replacement of marine ingredients in Asian aquafeeds	Animal and plant protein ingredients with potential for use in aquaculture are reviewed. Factors to consider for any ingredient, i.e. price, availability, composition, anti-nutrients, digestibility and effects on growth, performance and palatability are discussed. Research in Australian and Thailand is discussed. Invited paper.	Allan, G.L., 1996. Potential for replacement of marine ingredients in Asian aquafeeds. In: Feed production on the threshold of the next age. Proc. Victam-Asia Conference. Bangkok, Thailand, 14-15 November. Victam International, The Netherlands, pp. 125-152.	1, 2, 3

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
24	Alternative feed ingredients for intensive aquaculture	Animal and plant protein ingredients are reviewed with emphasis on Australian agricultural ingredients. An invited paper, based on Allan, 1996.	Allan, G.L., 1997. Alternative feed ingredients for intensive aquaculture. Recent Advances in Animal Nutrition in Australia. University of New England, Armidale, 30 June to 1 July, 1997, pp. 98-109.	1, 2, 3
25	Diet development; past successes and future challenges	Summary of global and Australian aquafeed demand and supply. Need for diet development and fishmeal replacement defined. Coordinated research in Australia is described and a summary of findings to date presented.	Allan, G.L., 1997. Diet development; past successes and future challenges. International Tasmanian Aquaculture Exchange, Hobart, 25-28 July, 1997.	all
26	Potential for pulses in aquaculture systems	Review of potential for increased use of pulses in aquafeeds. Constraints, including low protein, high carbohydrate and anti-nutirnets are described and methods of addressing these are reviewed.	Allan, G.L., 1997. Potential for pulses in aquaculture systems. In: R. Knight (ed.). Linking Research and Marketing Opportunities for Pulses in the 21st Centure. Proc. Third Intnl. Food Legumes Research Conference. Kluwer Academic Publishers, pp. 507-516.	1, 2, 3
27	Fishmeal replacement in aquaculture diets using rendered protein meals	Summary of research on use of animal proteins in aquafeeds for silver perch (ACIAR and FRDC), prawns and barramundi (FRDC). Success with total replacement of fishmeal with meat meal for barramundi; replacement of most (5% fishmeal in diets) for silver perch and replacement of half for prawns described. Large-scale pond trials and laboratory studies plus taste panel studies are described.	Williams, K.C., Allan, G.L., Smith, D.M., Barlow, C.G., 1997. Fishmeal replacement in aquaculture diets using rendered protein meals. Fourth International Symp. on Animal Nutrition, Protein, Fats and the Environment, Melbourne, 24-26 September, 1997, pp. 13-26.	1, 2, 3, 5
28	Aquaculture development – a state perspective from New South Wales	Overview of aquaculture – constraints to development – including problems with aquafeeds and ingredient supply (especially fishmeal).	Allan, G.L., 1998. Aquaculture development – a state perspective from New South Wales. Outlook ’98 Conference, Canberra, 3-5 February, 1998. ABARE. pp. 284-292.	Overview
29	Potential for pulses	The potential for grain legumes including peas, beans and lupins for use in aquaculture diets is discussed.	Allan, G.L., 1998. Potential for pulses. International Aqua Feed 2, 17-20.	1, 2, 3
30	Fishmeal replacements for shrimp and fish feeds in Australia	Review in technical terminology of need for fishmeal replacement and coordinated approach to this research with silver perch, prawns and barramundi in Australia.	Allan, G., Williams, K., Smith, D., Barlow, C., Rowland, S., 1999. Fishmeal replacements for shrimp and fish feeds in Australia. International Aqua Feed 4, 10-16.	1, 2, 3, 5
31	New and better paths to farmed fish nutrition	This article was commissioned by ACIAR to describe in non-technical terms the justification for fishmeal replacement research in Thailand and Australia and to summarise the outcomes from the projects.	Beckmann, R., 1999. New and better paths to farmed fish nutrition. Partners in Research for Development 12, 42-46.	All
32	Silver perch nutrition and feeding	This is a book chapter commissioned by CAB International Publishers for “Nutrient Requirements and Feeding of Aquaculture Fish” edited by Lim and Webster	Allan, G.L., Rowland, S.J., 2000. Silver perch nutrition and feeding In: Webster & Lim (eds.) Nutrient Requirements and Feeding of Aquaculture Fish. CAB International Publishers. In Press. 1-26.	All

Table 2. Summary of Major Conclusions in Thailand (All papers collected as Appendix 2)

App. No.	Description of Work	Conclusions	Publication	Objectives Addressed
1	Quantifying dietary protein level for maximum growth and diet utilization of Hybrid *Clarias* Catfish	At constant digestible energy level (2.7 kcal/g), protein level for maximum growth and diet utilization is 40%.	Jantrarotai, W., Sitasit, P., Sermwatanakul, A. (1996). Quantifying dietary protein level for maximum growth and diet utilization of hybrid *Clarias* catfish. J. Appl. Aquacult. 6, 71-79.	4
2	The estimation of the economic protein requirement of Hybrid *Clarias* Catfish	The maximum economic returns were obtained when dietary protein range from 33-36%.	Jantrarotai, W. (1995). The estimation of the economic protein requirement of hybrid *Clarias* catfish. Kasetsart J. (Nat. Sci.) 29, 38-44.	4
3	Protein and energy levels for maximum growth, diet utilization, yield of edible flesh, and protein sparing of Hybrid *Clarias* Catfish	Dietary digestible energy of 3.2 kcal/g provided by carbohydrate to lipid ratio of 2:1 spare dietary protein and maximum growth and diet utilization can be achieved at 35% protein level.	Jantrarotai, W., Sitasit, P., Jantrarotai, P., Viputhanumas, T., Srabua, P. (1996). Protein and energy levels for maximum growth, diet utilization, yield of edible flesh and protein sparing of hybrid *Clarias* catfish. Paper presented at the Annual Meeting of the WAS, Bangkok, Thailand, pp 281-289	4
4	Comparison on the efficacy of different carbohydrates as energy sources for Hybrid *Clarias* Catfish	Hybrid catfish utilize wheat flour best and equally utilize sucrose, dextrin, corn starch, rice starch, glutinous rice starch and manoic starch as energy sources with high efficacy.	Jantrarotai, W., Jantrarotai, P., Sitasit, P., Viputhanumas, T. (1996). Comparison on the efficacy of different carbohydrates as energy sources for hybrid *Clarias* catfish fingerlings. Kasetsart J. (Nat. Sci.) 30, 56-63.	3
5	Effects of dietary fibre and its optimum levels for growth of Hybrid *Clarias* Catfish.	Synthetic cellulose at levels up to 15% had no effect on fish performance. However, when rice hull was used as fibre source, the level about 5% seemed to suppress fish growth.	Jantrarotai, W., Tewpanich, N. (1998) Effects of dietary fiber and its optimum levels for growth of hybrid *Clarias* catfish. Kasetsart J. (Nat. Sci) 32: 13-23.	3, 4
6	The maximum carbohydrate from raw broken rice to lipid ratio in Hybrid *Clarias* Catfish diet.	The diet with the 33% protein and gross energy of 430 kcal/g could contain up to 50% of native carbohydrate from raw broken rice which is equivalent to 52.5% of raw broken by weight. However, the lipid level in such diet should not be less than 4.4% to maintain carbohydrate:lipid of 11.23:1.	Jantrarotai, W., Sitasit, P., Rajchapakdee, S. The maximum carbohydrate from raw broken rice to lipid ratio in hybrid *Clarias* catfish diet. (Internal publication). Also published as: Jantrarotai, W., Sitasit, P., Rajchapakdee, S. (1994). The optimum carbohydrate to lipid ratio in hybrid *Clarias* catfish (*Clarias macrocephalus x C. gariepinus*) diets containing raw broken rice. Aquaculture 127(1): 61-68.	3, 4
7	Optimum levels of essential fatty acids for growth and feed conversion of Hybrid *Clarias* Catfish	The optimum levels of essential fatty acids in diets range from 1.0-1.5% for n-6 and 0.8-0.9% for n-3.	Jantrarotai, W., Somsueb, P. (1995). Optimum levels of essential fatty acids for growth and feed conversion of hybrid *Clarias* catfish. Kasetsart J. (Nat. Sci.) 29, 479-485.	4
8	Nutritional studies in Hybrid *Clarias* Catfish for developing complete catfish feed.	The optimum levels of protein, fat, carbohydrate and essential fatty acids which resulted in maximum growth and diet utilization were 36-40%; 4-10%; 37-50% (raw starch) or 28-39% (cooked starch); and 1.0-1.5% (n-6) and 0.5-1.0% (n-3) respectively.	Jantrarotai, W., Somsueb, P., Sitasit, P. (1995). Nutritional studies in hybrid *Clarias* catfish for developing of complete catfish feed. Proceedings of 33rd Kasetsart University Annual Conference. (Abstract only).	4
9	Effects of phospholipids in diets on performances of Hybrid *Clarias* Catfish	The optimum level of soybean lecithin (as phospholipids source) for growth and performances was 3% in the diet (without choline chloride).	Kosutarak, P., Pupipat, T. Effect of phospholipids in diets on performances of hybrid *Clarias* catfish. (Manuscript form only – in press). 1-12.	3

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
10	Protein sparing effect by energy with a low ratio of carbohydrate to lipid in diets for Hybrid *Clarias* Catfish	Energy sources and energy levels in diets for hybrid *Clarias* catfish significantly affected protein and energy requirements of fish for optimum growth, diet utilization and yield of flesh. Diets containing energy with a low ratio of carbohydrate to lipid spared protein and lowered protein requirements of hybrid catfish from 40-35%. With proper energy sources increased energy levels from 275 to 325 kcal/100 g increased growth of fish and also spared protein in the diets.	Protein-sparing effect by energy with a low ratio of carbohydrate to lipid in diets for hybrid *Clarias* catfish. (Manuscript form only – in press). 1-13.	4
11	Digestibility coefficients of practical feed ingredients available in Thailand for Hybrid *Clarias* catfish (*Clarias macrocephalus x Clarias gariepinus*).	The apparent digestibility coefficients (ADCs) for dry matter and protein of the animal protein ingredients were 94.6 and 93.3% for low ash fishmeal, 92.6 and 90.4% for poultry meal and 78.9 and 79.3% for bloodmeal. High ash fishmeal was digested only 58.7% for 60.5% in dry matter and protein, respectively, although ADC for energy was high (85.5%). Hybrid catfish digested plant protein quite effectively with range 76.5-99.5%. ADCs for energy in plant protein ingredients range 64.5-82.7% and ADCs for dry matter were dsignificantly low for high fibrous ingredients especially kapokseed meal (32.2%), cottonseed meal (42.4%) and whole lupin (59.5%). Hybrid catfish effectively digested rice bran, steamed and ground broken rice as energy sources. The ADCs for energy of these ingredients range 70-80%. However, the fish poorly digested dry matter and energy from whole broken rice, cassava and steamed cassava.	Jantrarotai, W., Allan, G.L., Kosutarak, P., Booth, M. (1998). Digestibility coefficients of practical feed ingredients available in Thailand for hybrid catfish (*Clarias macrocephalus* x *Clarias gariepinus*). Presented at Aquaculture '98, Las Vegas, USA. 1-6.	1, 2
12	Minimum ratio of fishmeal and soybean meal protein with no effect on growth, diet utilization and feeding rate of Hybrid *Clarias* Catfish (*Clarias macrocephalus x Clarias gariepinus*).	50% of the fishmeal (Thai) protein can be replaced by soybean meal. All soybean meal diet and soybean meal + methionine diet did not support normal fish growth.	Sitasit, P., Jantrarotai, W. (1997). Minimum ratio of fishmeal and soybean meal protein with no effect on growth, diet utilization and feeding rate of hybrid catfish. Technical Paper no. 4. Div. Aquafeed Quality Control & Development, Chatuchak, Bangkok. 1-13.	3
13	Comparison on efficacy of Hybrid *Clarias* Catfish diets formulated from nutrient requirement data to a selected commercial catfish feed.	Ten practical diets formulated from nutrient requirement data and contained various conventional feedstuffs were superior to the commercial feed. Among the 10 diets made, those containe 35% protein, 3.0-3.3 kcal DE/g, were best. Ingredient quality play a major role in diet utilization of fish.	Jantrarotai, W., Sitasit, P., Pupipat, T. (1996). Comparison on efficacy of hybrid *Clarias* catfish diets formulated from nutrient requirement data to a selected commercial catfish feed. Technical Paper no. 179. National Inland Fisheries Inst., Bangkok, Thailand. 1-20.	3

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
14	Use of fish oil, fish silage and fish soluble extract as attractants in diets for Hybrid *Clarias* Catfish.	This experiment attempted to replace fishmeal with soybean meal (64.46% of the diet) by using various attractants such as fish oil, fish silage and fish soluble extract. There was no effect of using these attractants to improve the palatability and utilization of the diet that contained 64.46% of soybean meal.	Kosutarak, P. Use of fish oil, fish silage and fish soluble extract as attractants in diets for hybrid *Clarias* catfish. (Manuscript form only – in press). 1-15.	3
15	Partially replacing fish meal with corn gluten meal improves growth, skin and flesh colouration of Hybrid *Clarias* Catfish.	Substitute 6-10% (by weight) corn gluten meal for fishmeal (Thai) in control diet promotes fish growth and skin colour of fish.	Jantrarotai, W., Viputhanumas, T., Somsueb, P. (1996). Partially replacing fish meal with corn gluten meal improve growth, skin and flesh coloration of hybrid *Clarias* catfish. Technical Paper no. 178. National Inland Fisheries Institute, Bangkok, Thailand. 1-17.	3
16	Use of chicken-head silaged for diet of Hybrid *Clarias* Catfish	Substitute 25% (by weight) chicken-head silage for trash fish or chicken-head (fresh) in the diets promote much better growth.	In press (Title only)	3
17	Use of dried layer waste in diets for the Hybrid *Clarias* Catfish	The maximum inclusion level of dried layer waste in the diet (30% protein) was about 24%.	Jantrarotai, W., Boonman, C. (1996). Use of dried layer waste in diets for the hybrid catfish. Internal publication but also published in Prog. Fish-Cult. 58, 273-276.	3
18	Use of silk worm pupae as substitute for fishmeal and soybean meal in diet for hybrid *Clarias* catfish.	Replacing 50% of fishmeal in standard diet with silk worm pupae caused 25% reduction in growth but FCR did not change. Partially or totally replacing soybean meal with silk worm pupae enhanced growth and utilization over the standard diet	In press (Title only)	3
19	Effects on growth, diet utilization and fish health of feeding Hybrid *Clarias* catfish diets with and without vitamin and mineral supplements.	Alternate-day feeding of diets with and without vitamin and mineral supplements could reduce feeding costs for fish.	Jantrarotai, W., Jantrarotai, P., Thabsing, R., Allan, G.L. (1996). Effects on growth, diet utilization and fish health of feeding hybrid *Clarias* catfish diets with and without vitamin and mineral supplements. Paper presented at the VII International Symp. on Nutrition and Feeding of Fish. Texas, USA.	4
20	Estimated feeding rates for sinking feed in comparison to satiated feeding of floating feed and the effect on performance of Hybrid *Clarias* Catfish	Elucidated feeding chart as guideline for feeding pond with sinking pellet	Jantrarotai, W., Viputhanumas, T. (1998). Estimated feeding rates for sinking feed in comparison to satiation feeding of floating feed and the effects on hybrid catfish performances. Proc. 36th Kasetsart University Annual Conference. 1-14.	7 (but for Thailand)
21	Effect of feeding regimes on performances of Hybrid *Clarias* Catfish	Based on weight gain, specific growth rate, feed efficiency and survival rate, feeding by hand-fed to satiety 2 times per day (900 and 1500 h) seemed to be optimum and was suggested for practical culture of hybrid catfish.	Kosutarak, P. Effect of feeding regimes on performances of hybrid *Clarias* catfish. (Manuscript form only – in press). 1-11.	7 (but for Thailand)

App. No.	Description of Work	Conclusions	Publication	Objective Addressed
22	Extension publications	1. The essence of feed and feeding of fish	❖ Jantrarotai, W. (1994). The essence of feed and feeding in fish. Extension Paper no. 25. National Inland Fisheries Inst., Dept. Fisheries, Chatuchak, Bangkok, Thailand. 1-44.	6
23		2. Special diets for broodstock	❖ Published in Thai Fisheries Gazette. pp. 235-240.	
24		3. Marine fish development	❖ Jantroratai, W. Marine fish feed development. pp.97-116	
25		4. Channel catfish nutrition and use of walking catfish pellet as feed for channel catfish	❖ Published in Thai Fisheries Gazette. pp. 551-558.	
26		5. Limitation of using growth, feed conversion ratio and survival rate as criteria for evaluating fish feed		
27		6. Recent developments in freshwater finfish nutrition in Asia	❖ Jantrarotai, W. (1996). Recent developments in freshwater finfish nutrition in Asia. In: Feed production on the threshold of the next age. Proc. Victam-Asia Conference. Bangkok, Thailand, 14-15 November. 1996. Victam International, The Netherlands, .pp 97-110. (Appendix copy is in manuscript form).	All
28		7. Farm-made Aquafeeds (12,000 copies of extension booklet) 8. Farm-made Aquafeeds video tapes	Copies of videos are available from Dr Geoff Allan, NSW Fisheries, Port Stephens Research Centre.	
	Extension workshops	Eight workshops have been organised. A total of 224 people have prticipated in these workshops.		6
	Presentation of papers	1. AADP Workshop Proceedings. Second Fish Nutrition Workshop, 25-27 October 1994, Singapore. (App. no. 24) 2. Proceedings of 33rd Kasetsart University Annual Conference, Bangkok, Thailand. 1995. (App. no. 8) 3. The Annual Meeting of WAS 1996. Bangkok, Thailand. (App. no. 3) 4. VII International Symposium on Nutrition and Feeding of Fish. Texas, USA, 1996. (App. no. 19) 5. VICTAM-ASIA '96 Conference. Bangkok, Thailand. (App. no. 27)		6

		6. Proceedings of 36th Kasetsart University Annual Conference, Bangkok, Thailand, 1998. (App. no. 20) 7. Aquaculture '98. The Triennial Meeting of National Shellfisheries Association Fish Culture Section-AFS. Las Vegas, Nevada, USA, 1998. (App. no. 11)		

1. BACKGROUND

This project involved collaborative research between NSW Fisheries, NSW Agriculture, Queensland University of Technology, CSIRO Division of Fisheries and CSIRO Division of Food Science and Technology to develop cost-effective diets for silver perch with an emphasis on replacing fishmeal in formulated feeds. The project had complementary aims to the silver perch component of the Fisheries Research and Development Corporation Sub-Program on Fishmeal Replacement. The research described here built on very promising results with evaluating the digestibility of a small number of Australian oilseeds and grain legumes in diets for silver perch.

In Australia, 27 312 t of fishmeal worth about AUS $17.5 million were imported in 1996/97 (ABARE, 1997). About 30 000 t of aquaculture feeds (almost all for carnivorous fish or prawns) are used each year in Australia. Assuming an average fishmeal content of 40%, this requires about 12 000 t of fishmeal. As high quality fishmeals are usually used for aquaculture feeds, with prices of up to $1 300 for 72% protein fishmeal (Danish fishmeal) and up to $1 000/t for 67% protein fishmeal (Chilean fishmeal), the cost of imported fishmeal for aquaculture diets may exceed $8 million each year. Aquaculture in Australia is expanding rapidly, as is the price of fishmeal.

Australia currently imported 121 437 t of edible seafood products (worth $601.6 million in 1996/97) each year including 90 289 t of fish and fish products (ABARE, 1997). Much of the fresh, chilled or frozen component (55 042 t worth $184 944 million) could be replaced by cultured fish. Replacement of fishmeal in aquaculture diets could prevent a massive escalation in the importation of fishmeal into Australia as well as lowering production costs and increasing the commercial viability of fish culture.

One of the major factors limiting the expansion of aquaculture is the development of nutritionally adequate, cost-effective diets. Feeds and feeding can contribute up to 70% of the total operating costs for fish and shrimp farms (Wee, 1992). The most expensive component of pelleted feeds is protein, of which 25-55% is required, depending upon whether the species is herbivorous, omnivorous or carnivorous (NRC, 1983; Lovell, 1989). The major protein source for most aquaculture diets is fishmeal (Lovell, 1989) and formulated diets can contain up to 60% fishmeal (Wee, 1992; New, 1991).

There are however, some major problems with fishmeal. Fishmeal and fish oil production is declining (Barlow, 1989). The aquaculture feed industry currently uses more than thirty million tonnes of the global fisheries catch (New and Wijkstrom, 1990), excluding `trash fish' fed directly to aquaculture species. As aquaculture production increases, demand for fishmeal will also increase, inevitably forcing prices to rise. As higher quality fishmeal is generally required for aquaculture feeds, species of fish currently used for Human consumption will increasingly be targeted by fishmeal manufacturers. In Malaysia much of the cheap fish used to produce salted fish for human consumption is now used for aquauclture instead (New, 1991). The reliance on fishmeal is one of the major negative factors invoked by recent anti-aquaculture literature (e.g. Naylor et al., 2000 - Effect of aquaculture on world fish supplies. *Nature* **405**:1017-1024).

Apart from a relatively small quantity of fishmeal produced in Tasmania during a limited period each year, very little fishmeal is produced in Australia (Foster, 1992). Most of the fishmeal required for aquaculture is therefore imported (ABARE, 1991) and of variable quality. Improved growth and food conversion efficiency have been recorded for salmonids when low-temperature fishmeals have been used. These special `aquaculture grade' fishmeals are more expensive than ordinary fishmeal, some by as much as 35% (Foster, 1992).

The project utilised collaboration between a number of institutions to compare and validate several experimental techniques to evaluate ingredients in diets for silver perch. Compared with warm blooded terrestrial monogastric animals, fish lose relatively little energy due to body heat production, and as measurement of non-faecal losses are much more difficult for fish than terrestrial animals, determination of digestibility is the recommended method for evaluating ingredients (Cho and Kaushik, 1990). Most commonly, faeces are collected by settlement, stripping or dissection and are then analysed (Cho *et al*., 1982). Nutrients or energy present in the faeces are subtracted from those in the feed to estimate digestibility (Cho and Kaushik, 1990). However, these *in vivo* methods of determining digestibility are expensive, time consuming and involve large numbers of fish and experimental tanks. When many potential feed ingredients need to be investigated, rapid *in vitro* methods for digestibility determinations may offer many advantages. A large number of potential feed ingredients can be screened in a short time, using very small quantities of material and very few animals, allowing identification of the few best performing ingredients that should be taken on to *in vivo* studies.

Several *in vitro* methods for digestibility determination have been advocated (Akeson and Stahmann, 1964, Hsu et al., 1977; AOAC, 1984; Grabner, 1985, Eid and Matty, 1989; Lan and Pan, 1993) and are being used by scientists at the Queensland University of Technology. Using these methods, ingredients are added to homogenates of fish guts and digestible enzyme activities are measured to assess ingredient digestibility. These methods perform quite satisfactorily, particularly in comparative studies (Neilsen *et al*., 1988; Lan and Pan, 1993) where a range of ingredients can be compared. They also perform well when the digestive capability of several animal species can be compared. In addition, comparison of *In vitro* digestibility with amino acid content can give specific information on the effects of processing on digestibility (Lan and Pan, 1993). Very good correlation between *in vitro* and *in vivo* methods of digestibility determination has been demonstrated (Grabner, 1985, Eid and Matty, 1989). In addition, good correlation between *in vitro* digestibility of fish meal and fish growth has been reported (Miyazono and Inoue, 1990).

There is also debate over whether digestibility is the best way to evaluate ingredients. An important limitation of digestibility techniques is the lack of discrimination between consumption, leaching and assimilation. In the assessment of dietary ingredients the latter is, of course, a key consideration. An alternative method of tracing the utilisation of formulated feeds by aquaculture species is to use the stable isotope technique. To date, this refined technique has only been tested on penaeid prawns. This Project offers the opportunity to examine the potential of the stable isotope technique in nutritional studies of silver perch and to compare results with those obtained from digestibility determinations and following analyses of whole fish carcasses in synchronised ingredient evaluation trials.

Promising ingredients will be evaluated using the most appropriate techniques and practical, cost-effective techniques to improve the digestibility and availability of lower quality (compared to fishmeal) ingredients will be developed. The involvement of the CSIRO Division of Food Science and Technology in this Project (and the entire Sub-Program) will enable fish nutritionists to utilise the latest technology to process ingredients to improve their value in fish diets. In particular, scientists at the CSIRO Division of Food Science and Technology are independently developing technology to fractionate grain legumes to isolate carbohydrate components for use in human foods. The by-products of these are protein enriched, carbohydrate reduced materials which may be cost-effective ingredients for fish feeds. Through contact with commercial food processes, industrial technology to cook or modify ingredients will also be accessed and evaluated. The Division is also purchasing the first pilot-scale, twin-screw extruder in Australia and the Sub-Program will have access to this unit. This extruder will be used to process ingredients and whole diets and be capable of handling small batches of about 50 kg. In the past, the minimum batch size for experimental diets needed for extrusion has been about 1 tonne, greatly restricting the ability of researchers to manipulate and evaluate the variety of factors affecting diet extrusion.

When high quality protein sources like fishmeal are replaced with lower quality ingredients, deficiencies in essential nutrients are likely. This Project will identify which nutrients will be the most limiting and the most expensive to supply.

Protein which is supplied in excess of requirements for growth and metabolism is used for energy and might be replaced by other energy sources such as well-digested carbohydrates or fats (El-Sayed and Teshima, 1991; Murai, 1992). Determination of optimum protein contents and protein to energy ratios could lead to significant reduction in protein contents of diets. As alternative protein sources to fishmeal are usually lower in protein, lower protein requirements would increase the choice of ingredients which could be considered as protein sources.

As the amino acid balance and fatty acid profile of alternative protein sources to fishmeal is often inferior, requirements for limiting amino or fatty acids could also limit potential for fishmeal replacement. Requirements for the most important limiting nutrients will be determined for silver perch.

Results from this project will be used to build a comprehensive feed data matrix for use in linear least-cost computer programs to formulate feeds for silver perch. These programs require information on nutritional requirements, and digestibility, restrictions, cost and availability of ingredients. At present these programs are run on assumptions about requirements and ingredients. This project will replace many of these assumptions with rigorous experimental data which will greatly improve the ability to formulate cost-effective diets for silver perch.

Two other projects relate to this one:

1. The Grain Research and Development Corporation funded a preliminary study to evaluate four oilseeds and grain legumes for silver perch. This project overlapped with the ACIAR project by approximately six months.

2. The Australian Fisheries Research and Development Corporation (FRDC) funded a Sub-program involving 13 collaborating research institutions involved on research with silver perch, tiger shrimp, barramundi and salmon to replace fishmeal in aquaculture diets. The ACIAR and FRDC projects had complementary aims but each focused on different aspects. The following table highlights the similarities and differences:

		ACIAR	FRDC
1.	Species	Focus on one species in Thailand – hybrid catfish and one in Australia – silver perch (*Bidyanus bidyanus*).	Broad ranging covering penaeid prawns (*Penaeus monodon*), barramundi (*Lates calcarifer*), silver perch (*Bidyanus bidyanus*) and Atlantic salmon (*Salmo salar*).
2.	Feeding habits	Omnivores	One omnivore, rest carnivores.
3.	Aquaculture industry	Relatively low-value products for high volume production for domestic consumption. Silver perch production will reduce imports of low-value fish in Australia.	High-value products, with export market potential.
4.	Primary beneficiaries	Small scale, low-income fish farmers in Thailand. Producers of relatively low-value fish in Australia. Commercial feed manufacturers and agricultural sector are secondary beneficiaries in Australia.	Aquaculture industries generally. Focus on producers of high-value species (except for silver perch farmers).
5.	Review and analysis of available and potential ingredients	Will be done in collaboration with FRDC Project.	Will be done in collaboration with ACIAR Project.
6.	Evaluation of digestibility of potential ingredients & determination of maximum inclusion levels of these ingredients	Emphasis on currently available ingredients.	Emphasis on new or `improved ingredients' e.g. protein enriched fractions or specifically developed abattoir by-products.
7.	Improvements to ingredients	Evaluate commercially available amino acids.	Evaluate processing (e.g. cooking & extrusion) of enzymes, and specifically developed amino acid supplements.
8.	Determination of nutritional requirements	Protein requirements and protein to energy ratios.	Requirements for essential amino acids and, if necessary, essential fatty acids.

2. OBJECTIVES

1. To thoroughly review available ingredients which have the potential singly, or in combination with other ingredients, to replace fishmeal or `trash fish' in aquaculture diets.
2. To determine the digestibility of alternative protein sources to fishmeal.
3. To formulate, using digestibility data, nutritionally balanced diets using alternative ingredients to fishmeal or `trash fish' and to compare performance of fish on these diets with that of fish on fishmeal diets.
4. Determine optimum protein requirements and the potential for `sparing' protein using fat or carbohydrate.
5. To determine the potential use of commercially available, synthetic amino acid supplements in fish diets.

This project was reviewed in 1996/97 by Drs Williams and Wee and Professor Wiang. The reviewers recommended the project be continued in both countries with the following extra objectives (expanding on Objectives 1 and 2 and adding two new objectives – 6 and 7):

1.1. Expand databases on Thai ingredient availability and cost.

1.2 Analyse ingredients for energy and amino acids (and proximates if this information is missing for some ingredients).

2.1. Measure digestibility of more ingredients with hybrid catfish.

6. Implement an effective and widespread extension program to ensure results benefit farmers (particularly in Thailand).

7. Undertake research in Australia to improve feed management for silver perch.

3. DESCRIPTION OF PROJECT

3.1. General Methods

An experimental approach to the problem was adopted. Initially, agricultural ingredients in both countries were identified (by region in Thailand) and then their potential was evaluated by:

1. Assessing proximate composition
2. Assessing availability and price
3. Measuring digestibility (of many ingredients)
4. Estimating utilization and maximum amounts which could be used in diets (of most promising ingredients).
5. Determining requirements for major nutrients. This was essential as nutritional requirements for silver perch and hybrid walking catfish were not established prior to this project. It is very difficult to maximise the use of agricultural ingredients which are generally inferior to fishmeal or trash fish in terms of nutrient content, without knowing minimum dietary nutrient contents necessary to satisfy the requirements of the target species.
6. Formulate and evaluate diets based on alternative ingredients to fishmeal or trash fish.
7. Optimise feeding practices for new diets.
8. Effectively transfer results to feed manufacturers and farmers.

Specific methods are provided in detail in the attached publications which have arisen from the project.

3.2. Staff Engaged

NSW Fisheries
Dr Geoff Allan[1]
Ms Jane Frances[1]
Mr David Stone[2]
Mr Scott Parkinson[3]
Mr Mark Booth[3,4]
Mr David Stone[2]

Thailand Department of Fisheries
Dr Wimol Jantrarotai[6]
Dr Pairat Kosaturak[6,7]
Mr Thummarch Boonmoon[3]
Mr Somchock Meeseang[3]
Mr Sunan Pandar[3]
Ms Naruemon Tewpanich
Ms Skirat Tangcharoenkitkul[3,8]

1 Funded by NSW Fisheries
2 Employed by complementary FRDC project
3 Employed by ACIAR project
4 Replaced Scott Parkinson
5 Casual, part-time employee
6 Funded by Thailand Department of Fisheries
7 Replaced Dr Jantrarotai in final year of the project
8 Replaced Ms Naruemon Tewpanich

3.3. Other Research Grants and Linkages

In Australia, silver perch nutrition research with complementary objectives to those of the ACIAR project was funded by the Fisheries Research and Development Corporation (FRDC) through the Fishmeal Replacement Sub-Program. This Sub-Program involved 13 collaborating research institutions and companies within Australia and research on four species including silver perch, barramundi, tiger shrimp and salmon. Six linked projects were coordinated by Dr Geoff Allan. Following the conclusion of the Fishmeal Replacement Sub-Program in 1996, the FRDC funded another Sub-Program on Aquaculture Diet Development. This was also coordinated by Dr Geoff Allan. The second Sub-Program involved six institutions and three projects on ingredient evaluation, nutritional requirements and diet validation and feeding strategies. Supplementary funding from the Grains Research and Development Corporation, the Meat Research Corporation, and the Australian Wheat Board, Ridley Agriproducts and Gibsons Ltd (the latter two are commercial aquafeed manufacturers) was obtained.

In Thailand, informal links were made with nutritionists at the Asian Institute of Technology and, through participation in conferences, with research workers in other countries in the region. Extension activities have involved the Department of Fisheries Offices throughout Thailand.

4. PROJECT ACTIVITIES – FINAL YEAR

In the final year of the project, the objectives recommended by the review team were met. These objectives were:

1. Expand database on Thai ingredient availability and cost.
2. Analyse ingredients for energy and amino acids (and proximates of this information is missing).
3. Measure digestibility of more ingredients with hybrid catfish.
4. Improvement of widespread extension plan to ensure results benefit farmers (particularly in Thailand).
5. Undertake research in Australia to improve feed management for silver perch.

Australia

In Australia, research to determine the most appropriate feeding strategies for fish of different sizes, cultured under different temperatures, commenced. Data generated have now been used to formulate feeding recommendations based on experimental data (see Table 3).

Table 3. Suggested feeding rates and frequencies for fingerling and large silver perch at different water temperatures

Water temperature (°C)	Fingerlings (2-50 g) rate (% body wt d^{-1})	Frequency (times d^{-1})	Large Fish (> 50 g) rate (% body wt d^{-1})	Frequency (times d^{-1})
10 - 12	0.5	1	0.5	alt. days
12 - 15	1	1	1	1
15 - 20	2.5	1	2	1
20 - 25	5	2	3	2 (50-350 g)
			2	2 (> 350 g)
25 -30	7.5	2	2	2 (50-350 g)
			2	1 (> 350 g)

Early recommendations in feeding strategies were published (see Appendix 1, item 22) and updated, experimentally-determined recommendations submitted for publication in a CABI book chapter (see Appendix 1, item no. 32).

Results were extended to farmers and feed manufacturers through individual farm or plant visits, presentations and seminars at industry field days and workshops, scientific committee meetings coordinated through the FRDC Sub-program presentations at Conferences and publications (for Australia see Appendix 1).

Thailand

In the final year, increased emphasis was placed on expanding the database on Thai ingredients and digestibility coefficients (objectives 1-3 for final year, above). Analyses of and digestibility coefficients for 10 new protein (animal and plant protein sources) and carbohydrate ingredients were determined (see Appendix 2, item 11). In addition, additional research with soybean meal, chicken-head silage and dried layer waste was completed (see Appendix 2, items 12, 16, 18).

Although not specifically recommended by the review team, additional research in Thailand was also conducted on feeding regimes (see Appendix 2, items 20, 21).

Most importantly, the emphasis of final year activities in Thailand was on extension activities. Eight farmer orientated workshops were organised and a total of 224 people participated. In addition, a non-technical extension booklet advising on farm-made aquafeeds in non-technical language was published (2 000 copies). This publication was so successful that Thai Department of Fisheries Extension published (at no cost to the project) an additional 12 000 copies (see Appendix 2, item 28.7). Several video tapes were also made and the project was featured on free-to-air television in Thailand (see Appendix 2, item 28.8). Copies of these videos are available on request from Dr Geoff Allan, NSW Fisheries, Port Stephens Fisheries Centre.

5. RESEARCH RESULTS AND OUTCOMES

Development of low-cost effective diets has been of critical importance to the development of the silver perch farming industry in Australia. This industry is expanding rapidly. Nutritional research by NSW Fisheries (including that under this ACIAR project and the complementary FRDC project) has led to the development of diets based on Australian agricultural ingredients such as meatmeal, poultry offal meal, lupins, field peas, canola and wheat with no need for expensive imported ingredients such as fishmeal. These diets have been adopted by commercial feed manufacturers (some have retained 5% fishmeal) and the cost of feeding silver perch has now been reduced to around $1.00/kg of fish. The overall cost of production on efficient farms is below $5.00/kg.

Annual production in NSW doubled each year from 2.6 tonnes in 1992/93, to 81 tonnes in 1996/97, and around 250 tonnes in 1997/98. An additional 30-50 tonnes are farmed annually in Queensland. There are around 400 ha of ponds completed or under construction in NSW and Queensland. Currently there is a low proportion of permit holders producing fish, and a small area of ponds under culture. Most operational farms, and consequently the industry as a whole, are inefficient and not producing any where near their potential. Successful nutrition research and subsequent commercial diet development combined with the production capacity of silver perch in ponds and the large number of licenced, but unproductive or inefficient farms, provide the basis for a dramatic increase in production over the next 5-10 years. If the industry realises this potential, it will become one of Australia’s largest fisheries.

In Thailand, research under the ACIAR project has provided a sound base for diet development from the hybrid walking catfish (*Clarias macrocephalus* x *C. gariepinus*). In similarity with the situation with silver perch, this is the first major nutrition study conducted with the hybrid walking catfish. It has become clear that the hybrid walking catfish has somewhat different nutritional requirements compared with either parents.

Partly as a result of this project, hybrid walking catfish culture has expanded enormously in Thailand. Estimates of catfish production in Thailand when the project commenced were about 50 000 t/yr. Recent figures suggest current production now exceeds 60-70 000 t/yr. The project has contributed to this expansion by making technology for nutritionally adequate farm-made diets widely available. This has been achieved through a focused, comprehensive extension program involving extension articles and booklets (over 12 000 copies of one of these have been printed), video presentations (screened on national television) and farmer-orientated workshops (over 220 people have received comprehensive training in farm-made feeds).

5.1. Impact and Future Directions

There are a number of possible future directions to the work. These include:

- Continuing to expand extension for farmers and feed manufacturers involved in both silver perch and catfish industries.
- Determining requirements for expensive nutrients not determined during the present study. Particular focus is warranted on polluting nutrients such as phosphorus and expensive vitamins such as biotin and inositol.
- Expanding evaluation of new ingredients in both countries.

In both countries, this project has facilitated the development of rigorous, effective nutrition research teams and well equipped facilities for laboratory-scale and commercial-scale research.

Especially for Thailand, this is a very important achievement. Sing Buri, the Department of Fisheries Station where experiments have been conducted, is now recognised as a nutrition “centre of excellence” within Thailand. Unfortunately, much of the other research on diet development throughout south-east Asia has lacked rigour and, more importantly, lacked effective transfer to commercial farmers. One strongly recommended future direction is the use of the Thailand nutrition research team to develop nutrition research capacity in neighbouring countries and to train researchers and government employees to transfer results and technology to low-income fish farmers.

5.2 Publications

See Tables 1 and 2 of the Executive Summary for a complete list. Copies of publications have been collected as Appendices (Appendix 1 for Australian publications and Appendix 2 for Thai publications) and are available on request from Dr Geoff Allan, NSW Fisheries, Port Stephens Fisheries Centre.

Other titles in this series:

ISSN 1440-3544

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project no. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters. Final Report to Fisheries Research and Development Corporation. Project no. 94/024.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 95/151.

No. 4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. Final report to Cooperative Research Centre for Freshwater Ecology.

No. 5 Kennelly, S.J. and Broadhurst, M.K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). Final Report to Fisheries Research and Development Corporation. Project no. 93/180.

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