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Final Report

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1 Acknowledgments

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Significant capacity building was provided by NFA, UNSW and ANSTO in Australia, and NFA funded training at AIT in Thailand for project team members and lead farmers. NFA also ensured the project linked to its other programs to maximise impacts. Sister Pauline Kagl and Matthew Ten from the Maria Kwin Training Centre are thanked for their contribution to the project, particularly the outreach work in remote villages and delivery of research findings via the TVET Certificate-level training. The Australian Institute for Nuclear Science and Engineering (AINSE) provided a Residential Scholarship to Lara Parata, and ANSTO provided a top-up scholarship for incoming John Allwright Fellow, Mr Joshua Noiney. ANSTO also funded additional sample analyses, and UNSW donated additional field equipment to support the research. Dr Sue Mei Lau, Head of the Department of Diabetes and Endocrinology, The Prince of Wales Hospital, helped to place the work in a human health context in our publications.

NFA staff played a critical role in transferring knowledge to many lead farmers, the NFA Fish for Prisons Program, and the NFA Fish for Schools Program, as well as a number of other outreach programs. NFA also provided support to our project partner, The Sisters of Notre Dame at the Maria Kwin Training Centre.

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The final year of the project was during the first year of the COVID-19 pandemic which significantly impacted travel, livelihoods, workloads and the wellbeing of our team and farming communities. The Project Leaders commend the project team for successfully completing all work whilst facing the challenges of COVID-19 in Australia and PNG. We note that the capacity building efforts of NFA, UNSW and ANSTO enabled the project team to carry out the remaining work without all team members together in the field. This success demonstrated the effectiveness and important of skill building.

We honour and acknowledge our past team members and colleagues, Wally Solato, Hopa Simon, Silas Kiafuli, Luana Yaman and Augustine Mobiha, who passed away during our program of research.

2 Executive summary

Small-scale, pond-based fish farming of Genetically Improved Farmed Tilapia (GIFT) is a rapidly growing food producing sector in Papua New Guinea (PNG). GIFT is largely farmed in earthen ponds that are often integrated into vegetable farms. There are now more than 60,000 small-scale fish farms in PNG, with most of the expansion occurring in remote rural areas. Protein deficiency and health impacts from undernourishment is common in PNG. Stunting of children and obesity in adults is associated with a high carbohydrate and low protein diet. More than 80% of the population lives on less than AUD $2.00 a day and unable to purchase protein. A lack of refrigeration in rural areas limits storage of meat from livestock.

Although fish farming is being widely adopted in PNG, farm yields are often low compared to yields in Asia where GIFT is widely farmed. The main bottlenecks for increasing fish production in PNG include poor access to low cost commercial feed and feed ingredients, lack of fish husbandry skills and poor quality fingerlings. This project was designed to build on a program of research funded by NFA and ACIAR, and coordinated by UNSW and NFA, to increase production by developing better farming technologies, mainly in fingerling production and fish feeding strategies.

The project established a knowledge baseline on the enablers and impediments to sustainable fishing farming by conducting a Political, Economic, Environmental, Scientific and Technological (PEEST) Analysis, a Strengths, Weakness, Opportunities and Threats (SWOT) Analysis and a Sustainable Livelihoods and Lifestyles Analysis (SLifA). This mixed method approach yielded valuable information on internal and external challenges to tilapia production in PNG, and helped to focus and frame the research and plan for dissemination of findings. The PEEST Analysis showed that government policies and legislation relating to aquaculture are generally supportive and create a solid basis for the promotion of aquaculture for food security and income generation in PNG. Small-scale, pond-based farming is addressing food security and creates income-earning opportunities in rural areas but not at a commercial scale for most farmers at present. Government policy to reinvest income from the non-renewable to the renewable sector is an opportunity to grow the industry; however, our SWOT Analysis has shown that poor infrastructure is a major impediment to scaling up production largely due to a lack of a road network to connect actors in the supply chain and provide access to farm inputs and markets, and to enable cold transport of farmed fish. The PEEST also revealed that the environmental impact of aquaculture in PNG is poorly understood and policy and decision making processes need to be revised, particularly to minimise impacts from rapidly growing sub-sectors such as cage-based farming. The PEEST Analysis found that technical capacity building of farmers and extension officers was a key enabling factor for the acceptance of aquaculture. Other technological advances such as the introduction of GIFT and cage culture have further strengthened the growth of fish farming. There is still a need to improve the capacity and numbers of trained personnel as well as the functionality of key institutions.

The SWOT Analysis echoed some of the findings of the PEEST Analysis. The key strengths of the industry included suitable soils and clean water for pond-based farming, a commitment by NFA and Government to support aquaculture development, and well-established social networks that facilitated sharing resources such as water, land, labour and knowledge. However, poor fish husbandry knowledge, lack of quality fingerlings, high cost of feeds, poor understanding of feeding strategies, and lack of infrastructure remain a major barrier to production, particularly in the rural areas of PNG. Nevertheless, there is an opportunity to meet protein demands through fish farming via research on fish feeding strategies, simple but effective methods of producing quality fingerlings; these findings from the SWOT reinforced the justification for the present project. The key threats to the industry included the risk of introduced fish pathogens, such as the Tilapia Lake Virus, climate change, tribal wars, competition for feed raw ingredients with other industries, escalating feed costs, sabotage of ventures and theft of fish.

The project surveyed over 700 farmers across 8 provinces (7 under the project and 1 by UNSW and NFA) as part of the SLifA survey. Farmers responses to the survey supported the findings of the PEEST and SWOT Analysis. Lack of infrastructure was a major barrier to accessing farm inputs and markets, despite farmers having suitable land and water resources for successful farming. Lack of fish farming knowledge and skills were also identified by farmers, with successful farming often attributed to access to training or being connected to a knowledge network via a wantok (Melanesian social support network based on reciprocity). The importance of capacity building was evident through the higher levels of success attained by farmers with a history of training by NFA and our ACIAR projects or access to our lead farmers who advocated better farming practices. Fish farming households with access to financial capital were better placed to attain livelihood goals and potentially to scale up production. It was found that more advanced farmers tended to have better financial assets established from other income sources or salaried positions. However, farmers who could not generate income still met the household protein requirements, and fish were also often shared with members of their extended family and Wantok thus increasing protein consumption outside of the farming household.

The project maintained two family lines of GIFT at HAQDEC and increased the number of brooders at the facility and with lead farmers. NFA refurbished the facilities at HAQDEC including the construction of a new hatchery to support the project and the fingerling supply program to farmers. NFA also renovated ponds at HAQDEC to support replicated fish feeding and husbandry experiments. With NFA funding, team members were trained in monosex fingerling production for the field trials. The HAQDEC team was able to produce > 99% all male fish and the facility is now supplying the monosex fingerlings to pond and cage-based farmers. This has resolved the problem of fish stunting due to breeding in the grow out stage at farms. Farmers have reported higher fish growth rates and improved feeding efficiency due to the absence of unwanted progeny which is a problem in ponds stocked with male and female fish. However, demand for monosex fingerlings has exceeded the capacity of HAQDEC's hatchery. NFA has now embarked on a program to establish satellite hatcheries across PNG and is training operators to produce monosex fingerlings.

Field trials comparing the contributions of nutrients from natural sources of food and commercial feeds, and the inclusion of inorganic fertiliser as a nitrogen source, were conducted. Stable Isotopes Analysis (SIA) and associated modelling identified key nutrient sources. The project demonstrated that for the low stocking densities used by small-scale fish farming, productivity and profitability could be increased by weekly application of commercial feed and by adding inorganic fertiliser to stimulate natural food production in earthen ponds. Our previous work under ACIAR Project FIS/2008/023 also supported weekly feeding over more expensive and wasteful daily feeding of fish, but had investigated organic rather than inorganic fertiliser. Our research also showed there are distinct microbiomes between fish under different feeding strategies; this information created a platform for future research on alternative nutrient sources for tilapia production, especially for higher intensity systems that could be developed for commercial-scale tilapia production in PNG.

Project outreach included farmer trainer days, post survey training of farmers, contributions to the Graduate Certificate coordinated by the Maria Kwin Centre, and technical inputs into the NFA Fish for Prisons and Fish for School programs. The project continued building the expertise of NFA's lead farmer program and expanded a knowledge network involving farmers, NGOs and partner agencies involved in aquaculture extension.

3 Background

Pond-based production of Genetically Improved Farmed Tilapia (GIFT) is rapidly expanding in the rural areas of Papua New Guinea (PNG) to the point that there are now more than 60,000 farms (Hiruy and Sammut., 2021; Sammut *et al.*, 2021a). Production levels are low when compared to those of Southeast Asia because of an inadequate supply of quality fingerlings, poor broodstock management practices and the cost and availability of formulated fish feed and fertilisers. Prior to the project, there was a general lack of knowledge of fish husbandry and pond management across PNG. Over 80% of the population of PNG is unemployed, and the majority of rural dwellers periodically or chronically experience protein deficiency in their diet due to the high cost of fresh meat and other animal-based protein. The National Fisheries Authority (NFA) requested a follow-on project from FIS/2008/023 in partnership with UNSW, a long-term collaborator, to continue research on resolving the constraints on the small-scale sector to improve food and income security in rural areas and to increase the social benefits of aquaculture. Food production, however, was the priority due to the overriding problem of protein-deficient diets for many people in PNG. Developing fish farming in rural areas is a priority of the Government of PNG, and the collaboration between UNSW and NFA has been the primary driver for research and management for this industry with funding from ACIAR and NFA, and major intellectual and in-kind contributions from UNSW, NFA and ANSTO.

The problems of under- and overnutrition are at great social, health and economic cost to PNG, particularly for the high rural population (Sammut *et al.*, 2021a). Child undernutrition alone was estimated to cost $USD 508 million in the financial year 2015-16 which is equivalent to 2.81% of PNG's annual GDP. Nutritional issues increase child mortality, lower income and productivity, and lead to a high cost of treating diseases associated with childhood undernutrition (Hurney, 2017). The increasing prevalence of adult obesity, type 2 diabetes and its life threatening co-morbidities, chronic heart disease and stroke pressures a nation that has a poorly resourced health system. These health issues will continue to increase the mortality rates of the people of PNG unless rapid solutions can be found to provide adequate nutrition to all sectors of the community. Protein is the key macronutrient of concern in PNG diets (Sammut et al 2021a).

To address protein shortages via small-scale fish farming, several bottlenecks for production needed to be cleared. The cost and availability of fish feed was the most significant economic constraint on small-scale fish farming in PNG when the project was designed. Over the last decade the availability of fish feed ingredients as well as commercially-produced feeds has declined due to diversion to the economically powerful new mining and liquefied natural gas ventures in PNG. Although fish will consume low-cost formulated feeds, the extent to which the formulations contribute to growth is uncertain. Nutrient requirements of fish from broodstock management to fingerling production, and from fingerling production to fish husbandry, and their supply under practical farming conditions, are important for sustainable aquaculture development. In PNG, the grow-out phase is when fish nutrition is most evident due to poor feeding strategies that leads to waste and high costs, a lack of access to quality feed, and an over dependency on vegetable garden waste that is low in protein.

Mixed sex fingerlings are problematic for fish farmers in PNG. Sexing of fish can only occur months after stocking and requires more effort by farmers to separate sexes. A consequence of not managing mixed sex ponds is an increase in the density of fish from breeding. This results in stunting of fish due to increased competition of fish for natural food and fish feed, and energy diverted away from growth to meet reproductive energy requirements. This leads to low yields and crops made up of stunted fish. Stunted fish are also sold as juvenile fish or fingerlings, intentionally and mistakenly. For small-scale farmers, producing a steady supply of fingerlings is important for their own venture and to enable them to earn additional income as suppliers of fingerlings. Quality fingerling supply is essential to the success of the industry. In recent times, monosex fingerling production has helped improve yields in other countries, but had not, until recently, been trialed in PNG where farmers struggle to produce table size fish due to fish breeding in ponds and progeny competing for food.

Inland aquaculture was identified as a priority area by ACIAR and NFA during the 2008 and 2011 country consultation processes and reaffirmed by the review of FIS/2001/083 and the mid-term reviews of FIS/2004/065 and FIS/2008/023. NFA has also promoted inland and coastal fisheries as priority areas for research and management to address food security and nutrition concerns for PNG and to increase the social benefits of aquaculture in the wider community; this is reflected in past and current NFA Corporate Plans (NFA, 2021a) and the recently released PNG Fisheries Strategic Plan, 2021 to 2030 (NFA, 2021b), This project was designed in accord with the PNG Vision 2050 (National Strategic Plan Task Force, undated) and the PNG Development Strategic Plan 2010-2030 (Department of National Planning and Monitoring, 2010a) which recommend development of agriculture, fisheries and aquaculture to overcome dependency on the mining and energy sectors. These plans are in line with the Millennium Development Goals espoused by ACIAR and NFA, the Australian Government's Development Strategy for PNG and the PNG Medium Term Development Plan (Department of National Planning and Monitoring, 2010b).

The project also sat within Subprogram 4 of ACIAR's country priorities for PNG; that is: small-scale inland aquaculture, including cost-effective feeds and feeding strategies and increased availability of quality fingerlings.

The main aim of this project was to resolve nutrition bottlenecks to fish production and to improve production of quality fingerlings, as well as to develop a deeper understanding of the factors that are drivers and impediments for small-scale fish farming. In keeping with NFA's primary goal for inland fishing farming, improving food production from inland aquaculture was the main focus of this project. Income security was nevertheless also considered, but as a secondary goal given the higher importance of addressing protein shortages in rural communities. Additionally, this project was designed to capitalise on the capacity built by earlier work and to expand the knowledge networks that had been established in partnership with NFA and other partners in PNG. These knowledge networks are important for transfer of project findings to fish farming communities across PNG. The project also invested heavily in building research and technical capacity in new research methods to evaluate the contribution of nutrients from different sources on the growth performance of fish, thus enabling NFA scientists and technicians to undertake higher quality research that is essential to long-term, locally-based aquaculture nutrition research.

4 Objectives

The overall aim of the project was to increase production of tilapia using low-cost and farmer-friendly technologies to improve food and income security as well as to increase the associated social benefits for smallholders and the wider community. The specific objectives of the project were to:

1. Evaluate the strengths, weaknesses, opportunities and threats to inland aquaculture in PNG and develop a sector-based strategic plan for NFA
2. Evaluate the social and economic benefits of aquaculture development in PNG
3. Improve broodstock management, fingerling production and husbandry technologies
4. Develop effective, low-cost feed formulations and feeding and fertiliser strategies

5 Methodology

Objective 1: To evaluate the strengths, weaknesses, opportunities and threats to inland aquaculture in PNG and develop a sector-based strategic plan for NFA

We employed an adapted Strengths, Weaknesses, Opportunities and Threats (SWOT) and Political, Economic, Environmental, Scientific and Technical (PEEST) Analysis for EHP, produced by Havini Vira under his Master of Philosophy at UNSW and supervised by A/Prof Sammut. Vira (2015) was reviewed as a basis for the adapted survey questions, interviews and focus group discussions. This was a team effort (Figure 1) and involved stakeholders from different agencies and also farmers. It was also a work-integrated capacity building exercise for the team. After the SWOT was first re-designed a pilot survey was conducted for a national analysis of the industry and questions were then updated to have relevance to more provinces and to address questions raised in the revised PEEST Analysis; the PEEST has since been revised again to incorporate new knowledge and changes to policy (Vira and Pandihau, 2020). The SWOT analyses also utilised baseline survey data from NFA and FIS/2008/023, and data generated by Objective 4. It will be updated by team on a regularly basis after the project.

PNG project staff were trained under this activity, along with Provincial Fisheries Officers. Related Sustainable Livelihoods and Lifestyle Analysis (SlifA) training was conducted by Dr Kiros Hiruy, who also produced a training manual for the participants (Figure 2). A/Professor Sammut, Dr Kiros Hiruy and Havini Vira trained project staff to produce a SWOT Analysis, interviewing techniques, running focus group discussions, transcribing, and data presentation for analysis and archiving. Human Ethics training was also undertaken to comply with ethical standards and ensure data could be published in high impact journals.

The SWOT/SlifA (Hiruy and Sammut, 2021) and PEEST Analysis (Vira and Pandihau, 2020) were based on an improved mixed-methods approach that involved semi-structured surveys, interviews, focus group discussions and document analysis. A literature review of policy, economic, environmental, social and technical issues that affect the aquaculture industry was undertaken and supplemented with qualitative data from interviews. Interviews were also used to determine if stakeholders considered the identified PEEST issues as factors that impact aquaculture development in PNG. To keep the focus on inland aquaculture, interviewees were selected from divisions or departments involved in the sector. In the provinces, staff of agencies involved in planning, agriculture and fisheries, gender and the environment were interviewed, along with NGOs involved in fish farming. The outcomes of the PEEST Analysis was used to establish the background to the SWOT Analysis and to identify key external trends. It was also used to underpin Objective 2.

External factors that influence aquaculture planning and interventions that were identified in the PEEST were validated by stakeholders at focus group meetings. Additional factors identified during the SWOT process were summarised from NFA interviews and a series of stakeholder workshops in each province. Proposed strategies to address factors raised in the SWOT process underpinned NFA's recent strategic aquaculture development planning. Outputs of the SWOT process were then validated in a provincial farmer's survey (7 Provinces by the project, and 1 by Shanice Tong from UNSW) under Objective 2.

Data from the interviews were processed using NVivo software to establish common threads and themes to compare and to consolidate the knowledge with the SWOT outcomes. Data cleaning and quality checking was performed at UNSW by Dr Angela Liu and checked again by Dr Kiros Hiruy and A/Prof Sammut. Some of the data were analysed using statistical methods to determine if SWOT factors identified influence farming in different district clusters. However, qualitative assessment was found to be more relevant due to some answers occurring at a low frequency thus preventing the application of statistics eg Chi Square analysis of cross tabulated data. The data from this research was also compared to baseline work by Smith *et al.* (2007) to establish the current status of freshwater aquaculture.

Structured surveys, focus group discussions and interviews from the PEEST and SWOT Analyses captured information that was used by the Aquaculture and Inland Fisheries Unit to produce a draft aquaculture strategic development plan as part of the recent Corporate Planning process and the production of NFA's Fisheries Strategic Plan, 2021-2030.

Figure 1: Core team and SPC staff at the project launch. The project team conducted a needs assessment to revise the project research strategy and identify areas of skill building, and also developed a project implementation plan that was regularly reviewed.

Reviews of existing policy and plans, undertaken by the PEEST Analysis, and stakeholder data were used to set short, medium and long-term goals, articulate NFA's vision, identify stakeholder needs and propose interventions against an implementation timeline. From this, the institutional requirements to grow the industry were identified and this information was used by NFA to formulate a strategic aquaculture development plan under Activity 1.4. Resource requirements to implement the plan were also identified by the NFA Aquaculture and Inland Fisheries Unit. The Executive Manager of the Aquaculture and Inland Fisheries Management Unit (the PNG Project Coordinator) took the lead to produce the strategic plan and undertake a cost-benefit analysis and determine resource needs.

Objective 2: Evaluate the social and economic benefits of aquaculture development in PNG

The activities of Objective 2 overlapped with the activities of Objective 1. Common team members participated in the activities of both objectives to ensure continuity and well-managed information transfer. Skill building from Objective 1 was also relevant to this activity. Additional training in social impact assessment was provided by A/Prof Sammut at in PNG and in UNSW, Australia. Dr Kiros Hiruy provided additional training in PNG. Staff were trained to conduct surveys and interviews, mine for data, organise data, scope information networks, and to conduct social evaluations using a range of qualitative and quantitative techniques that are taught at the postgraduate level for professionals – UNSW provided core training and also mentored staff. EIA practices, particularly social impact assessment methods, were taught at a professional level to enable team members in management roles to apply the knowledge to other projects run by NFA. Two project team members were also trained at UNSW under MPhil programs. Staff learned to analyse different data sets and to interpret and synthesise the results from the analyses, and to understand how the data can help shape policy.

Following the training, a research strategy and actions plans were developed and revised regularly. During critical periods of research activity, the team held monthly meetings to monitor progress and identify areas that required support via more training and mentoring. RDS Partners and UNSW mentored staff, particularly in the first set of field activities to ensure staff skills were properly developed and to identify any additional training needs and support. A pilot study was undertaken early in Year 1 to refine the surveys and interview techniques.

As for Objective 1, a mixed method approach was used to collect qualitative and quantitative data on social and economic benefits of aquaculture development with an emphasis on how the adoption of research findings and the extension activities can drive positive social and related economic changes. Data on gender and age-related benefits, and the potential for aquaculture to improve the social and economic outlook of other vulnerable groups were also evaluated. Focus group meetings, surveys and interviews of all stakeholders, including the wider community, were conducted at least annually and the findings shared with the communities that were involved during follow up visits by the team. All data were collected under a UNSW Human Ethics Approval. As for Objective 1, this survey work captured data on the different scales of the sector (predominantly small-scale, subsistence), the linkages or potential linkages between actors in the sector, and the potential to cultivate synergies between actors that could increase social and economic benefits.

A Sustainable Livelihoods and Lifestyle Analysis (SLifA) Framework was used in the mixed-methods design for Objective 2. The livelihood analysis framework is a tool that considers and analyses the household as the basic economic decision-making unit. Data were collected on human, natural, social, economic and physical capitals and included data drawn from the SWOT analysis under Objective 1 and baseline data from NFA's past and current farmer surveys. The framework is participatory. Thus, it was important that issues were analysed as identified by the populations under consideration – in this case, for instance, smallholder fish farmers in PNG. The framework looked at both the micro and macro-levels and the interaction between the two. It included an analysis of household assets, strategies, priorities and goals at the micro-level; and the policies, institutions and processes that affect livelihoods at national and international at the macro-level. As discussed above, training for SLifA was provided by Dr Kiros Hiruy in Year 1.

Figure 2. Some of the trainees at the SLifA workshop held in Mount Hagen. Over 30 people were trained in the SLifA approach, survey design, interview techniques and other associated methods. Photo: J.Sammut, UNSW.

Objective 3: To improve broodstock management, fingerling production and husbandry technologies

This objective was undertaken at HAQDEC due to security risks at local farms associated with political unrest during the election period, social conflicts in the highlands and thefts and sabotage at farms. It was largely a capacity building exercise rather than an experimental activity given that existing knowledge was available and some of the knowledge that was sought was generated by the team following completion of FIS/2008/023. The Year 1 needs assessment and NFA staff identified capacity building as the best investment to achieve this objective. We originally planned work with lead farmers at a variety of locations, but NFA advised to restrict the work to HAQDEC following improvements to the research station and increased security for the team and experimental infrastructure. NFA also wanted to ensure that a new hatchery to produce fingerlings could be tested on-site and not at risk from vandalism during the election period or other conflicts in the highlands. Team safety was also a priority, and at times, team members had to be evacuated from the area due to death threats. On farm work was conducted for Objective 4, but for collection of farm practices and production data rather than controlled experiments which could have resulted in lost data from thefts.

Broodstock management involved selecting fish from two families of GIFT we established under FIS/2008/023. Selection was based on growth performance. However, no significant differences were found in the growth performance of the two families and there was no need for any long-term trials to select better quality broodstock. We explored the possibility of bringing Western Province fish to HAQDEC but decided not to due to outbreaks of Tilapia Lake Virus around the world. Post project, NFA has organised quarantine procedures but fish were not available during the project timeline to compare to the two families that we previously established.

Post FIS/2008/023, it was established that the fecundity of brooders and the quality and survival of eggs was insignificant between families. Accordingly, this objective, following discussion with the team and the fisheries RPM at the time, was refocussed on capacity building of the team in hatchery design and evaluating the efficacy of new hatchery practices to produce quality fingerlings from the established family lines. To address this, NFA funded training of project staff in broodstock and hatchery management at AIT in Thailand. On return, the team, with funding from NFA, built a new hatchery using methods that are successfully used in Asia. The team also redesigned broodstock holding facilities. The hatchery set up was also designed to be eventually rolled out by NFA under a satellite hatchery program (now underway). The hatchery construction and operations were coordinated by Billy Kerowa who documented all stages from hatchery set up, operations and maintenance. Joshua Noiney and Micah Aranka were also involved, particularly for trials on producing mono-sex fingerlings and dissemination of that knowledge to lead farmers. It is noted that Jacob Wani's unit was responsible for funding this work which was also required to provide experimental fish for Objective 3. Although not part of the original intent of the project, an evaluation of the fingerling production issues early in the project reinforced the need to move farmers away from mixed sex to monosex fish production. This was also pushed by NFA as a priority. In response, NFA funded lead farmers and several team members to undertake further training at AIT in Thailand.

In Year 1, the main husbandry issue was, as described above, the difficulty of separating male and female fish. This was partly due to the time it takes for external sex differences to be noticeable, errors made by farmers, or a reluctance to separate sexes, either due to time commitment or disinterest. Our surveys found that farmers consistently reported stunted fish and struggles with sexing of fish, or not having sufficient ponds to separate sexes for growout separately. Of concern was the inability of farmers to differentiate fish based on age because of the stunting issue. These findings supported the need to focus on monosex tilapia production. Fish feeding, as a husbandry issue, was addressed under Objective 4. Accordingly, monosex fingerling production became a key capacity building activity, and on-farm practice of the method was undertaken as work-integrated learning and to evaluate the difficulties that farmers might face. All work was undertaken with human health and environmental safety protocols due to the use of Methyl Testosterone to produce all-males. This activity was led by Joshua Noiney who also taught lead farmers.

Objective 4: To develop effective, low-cost feed formulations and feeding and fertiliser strategies

This activity followed on from FIS/2008/023. The feed ingredients database was revised to incorporate new ingredients, their sources and proximate analysis data. Sample of ingredients were sent to UniTech for proximate analyses and details of the source of ingredients (supplier name, address, cost of ingredients, GPS coordinates) were entered into the database.

The outcomes recent trials conducted by FIS/2008/023 and Justin Narimbi (UNSW) were reviewed. This helped to narrow down efforts on feeding frequency and fertiliser selection.

The dietary pathways of natural and formulated feeds in the diet of tilapia were determined through analyses of carbon and nitrogen stable isotope values of fish and diet sources. Stable isotopes are naturally occurring stable atomic forms of carbon and nitrogen. Carbon and nitrogen isotopes ratios are used as a tracer of food source (Gopi et al; 2018; 2019a; Sammut *et al.*, 2021b). Generally the isotopic value of fish tissue is directly related to the isotopic values of their diet.

This activity involved comparing growth performance of tilapia fed with commercial feed with and without inorganic fertiliser and sweet potato in replicated ponds at HAQDEC. The cost of farm inputs was analysed to determine production costs, and, therefore, the profitability and the practicability of farming fish under different practices. The trials measured growth performance under Objective 3. At the end of the trials fish muscle tissue, pelleted feed, phytoplankton, zooplankton, algae and pond detritus were sampled from each replicate pond for isotopic analysis and to describe the hindgut microbiome and the likely role of bacteria in nutrient assimilation.

Mixing and mass balance models were used to calculate the relative contribution of each food source (Philips and Gregg 2003; Alderson *et al.*, 2013). Fish gut microbiomes from wild and farmed fish were compared to determine if bacterial communities play a role in digesting different sources of nutrients, and to better understand if alternative feed ingredients can replace existing ingredients in formulated feeds. Similarly, this helped to understand the extent to which fertilizers can improve natural food sources in ponds, which have been shown by Narimbi, Mazumder and Sammut (2018) to play a significant role in fish nutrition at the stocking rates used in PNG. This work involved Lara Parata, a UNSW, NFA and AINSE sponsored postgraduate student who also was involved in training the team and supervising fish nutrition trials with Joshua Noiney from NFA. The results were used to determine the relative contribution of food sources (natural and supplementary) to the diet of the fish in regularly fed and unfed (fertilised) ponds. The trials also generated information on the cost of ingredients and identified cost-based options relative to growth performance of tilapia.

ANSTO and UNSW staff trained the PNG-based project team in environmental and isotopic analyses (sample collection and preparation, data interpretation). Although they will be unable to analyse isotopes in PNG, they nevertheless now have the skills to collect and prepare samples that are sent to Australia, understand how they are processed, and then to interpret the results.

6 Achievements against activities and outputs/milestones

Table 1: Achievements and against activities and outputs/milestones

Objective 1: *To evaluate the strengths, weaknesses, opportunities and threats to inland aquaculture in PNG and develop a sector-based strategic plan for NFA*

No.	Activity	Outputs/ milestones	Date Completed	Comment
1.1	Conduct a PEEST Analysis	Team training and planning workshop (and inclusion of Fisheries Management Unit Staff)	Y1,m1	The team training facilitated an understanding of how the science and other technical components of the research could translate into better management, and created a stronger link between the activities of the technicians and researchers in the provinces and management staff in Port Moresby.
		Data on political, economic, environmental, scientific and technical factors will be compiled	Y1,m3	Completed
		Complete validation workshop	Y1,m4	Completed
		PEEST Analysis Report	Y1,m5	Report completed in March 2016; there will be a post-project revision to accommodate changes in the Fisheries Management Act, new aquaculture development strategies, and the latest NFA Corporate Plan. If funded, the proposed follow-on project will use this revision as a work-integrated learning activity for other staff. The original lead, Havini Vira, has left NFA.
		New activity under the variation: Update report based on institutional and operational changes NFA and updating of the PNG Fisheries Management Act	Y5, m3	The report was updated to include some policy changes; however, the project ended before further policy changes that relate to aquaculture were made. See above comment on follow up action.

No.	Activity	Outputs/ milestones	Date Completed	Comment
1.2	Conduct a SWOT Analysis using a mix-methods research design	Stakeholder workshops to gather lay knowledge	Y1,m6	Additional workshops were conducted at the end of each SLifA survey and via focus group meetings in 7 provinces. Shanice Tong conducted the same in East New Britain. These workshops also helped to frame future research and interventions.
		Conduct surveys and interviews with farmers, researchers and managers	Y1,m3-m7	At the project launch it was decided to integrate the survey questions for the SWOT Analysis with the SLifA survey to reduce effort in the field and avoid interview fatigue in the farming community. Nevertheless, the SWOT Analysis served the purpose under the project in that results were used to improve the SLifA work, and guided the research activities. Eight provinces were surveyed, including ENBP by Shanice Tong for her UNSW MPhil. Her results will be integrated into the SWOT Analysis report. NFA has expanded the surveys and we plan to integrate the data into the report, post project.
		New activity under variation: Conduct follow up interviews to address data gaps identified from the data analysis	Y4, m5 to Y5,m3	Additional interviews continued into the extension period and to the end of the project – the interview data are being analysed to complete a publication on the social impacts of inland aquaculture
		Data analysis of all available data	Y5,m3	Additional data have been added to update the analysis, including post project data collected by the team as part of their ongoing social impact assessment activities – this is further evidence of enduring impact from capacity building under the project
1.3	Produce a SWOT Analysis report	Completed interpretation of datasets	Y1,m12	Completed
		Draft SWOT Analysis and NFA workshop	Y2, m2	Completed
		Final SWOT Analysis Report and Stakeholder workshops	Y2,m4-m5 Y4 to end of project	The stakeholder workshops were scheduled as planned but a final workshop was scheduled for Year 5 (under the project variation) to provide a complete overview of the project's findings and to include updated information. However, due to COVID-19 travel bans, the final SWOT Analysis could not be presented in a workshop. We have integrated the SWOT information into other project documents and papers to support interpretation of related data sets.

No.	Activity	Outputs/ milestones	Date Completed	Comment
1.4	Produce a strategic plan for inland aquaculture development in PNG and conduct workshops to facilitate adoption of the plan	Stakeholder consultation – data and lay knowledge compiled	Y3, m4	Although the milestone was met, stakeholder consultation has continued because the industry and the socio-political landscape is changing. Post-project, NFA will continue, as it has independent of ACIAR projects, engage with stakeholders.
		Establish LFA and IPTT and train NFA staff on strategic planning process	Y4-6	Partially completed due COVID-19; however, Aquaculture and Inland Fisheries Unit team members completed the process which was integrated into NFA Corporate Planning and the NFA Fisheries Strategic Plan 2021-2030.
		Draft strategic plan and workshop with NFA, NDAL Provincial DAL	Y3, m6-m9 Y5, m5 Y5, m6	Completed by Aquaculture and Inland Fisheries Unit during COVID-19 lockdown and NFA strategic planning period and incorporated into the NFA Fisheries Strategic Plan 2021-2030 by Jacob Wani. No workshop was undertaken due to restrictions on staff movement during the pandemic.
		Published strategic aquaculture development plan	Y5,m6	Plan produced by the Aquaculture Unit and Inland Fisheries Unit, NFA; Policy Brief for next update is being prepared by the project team to incorporate findings from end of project findings.
		Workshop to facilitate uptake of plan		Workshop postponed due to COVID-19 and lockdowns in Port Moresby; to be undertaken under UNSW funding, post project.
1.5	Train NFA staff in SWOT Analyses and evaluation of socio-economic data	Skilled NFA staff	Y1,m1 Y2,m2 Y4,m12	Completed in 2015 and informal training has continued. However, skill building of staff has continued and NFA has adopted the skills for its own survey work.

PC = partner country, A = Australia

Objective 2: Evaluate the social and economic benefits of aquaculture development in PNG

No.	Activity	Outputs/ milestones	Date Complete d	Comments
2.1	Review findings of SWOT Analysis (Objective 1)	Team workshop to review findings and summary report on main findings	Y2,m2	Final meeting could not take place due to COVID-19. However, the team has interacted to review findings, work on future research plans, interpret and write papers, and discuss ways to integrate the results into survey work that NFA will conduct.
		Second review will be undertaken to address changes to the NFA structure that will be implemented during 2019	Y5, m3	The SWOT data were updated annually. The revised NFA Corporate Plan was launched in April 2021, as the project was closing. The restructure of NFA was also delayed and still in progress. Nevertheless, NFA and UNSW will undertake further reviews of SWOT findings as part of their long-term collaboration.
2.2	Analyse baseline data from NFA and FIS/2008/023	Analysed dataset	Y1,m2-3	These data, where useful, relevant and of appropriate quality, were integrated into the Activity 2.3

No.	Activity	Outputs/ milestones	Date Completed	Comments
2.3	Undertake qualitative evaluation with contextually effective methods, such as a Livelihoods Analysis Framework, to achieve sustainable livelihoods and to determine socio-economic impacts of research uptake	Scoping visit, workshop on survey and interview data	Y1,m1	Completed – over 30 participants were involved in the training workshop and all were involved in the survey work across 8 provinces.
		Assessment of stakeholder networks and existing and potential data sets	Y1, m1-2	Completed
		Surveys, interviews and other data collection	Y1, m3 to Y3,m8	Surveys and planned schedule of interviews work were completed. A large database was generated for over 700 farms in PNG. We note that NFA has adapted the survey for its other activities in PNG demonstrating the effectiveness of capacity building.
		Additional interviews to fill knowledge gaps from previous work	Y5,m2	Additional interviews were undertaken by NFA to fill knowledge gaps identified by the analysis of the SLifA survey and SWOT Analysis. COVID-19 slowed progress but the work was completed.
		Analysed and interpreted data set to inform subsequent data collection and feedback into project strategies and apply data to Livelihoods Analysis Framework	Y2,m2 – m8	We opted to prepare these two activities as papers for project team members to gain writing experience (eg Hiruy *et al.*, 2022-under review) and a book chapter with greater emphasis on the social and health impacts (Sammut *et al.*, 2022 - accepted)
		Socio-economic impact assessment report	Y5,m3	
		Peer reviewed publications	Y2-to end of project	One book chapter has been accepted; 3 papers area under review in a Q1 journal; 3 papers are under preparation.

No.	Activity	Outputs/ milestones	Date Complete d	Comments
2.4	Annual and final workshop to communicate findings and to research team and stakeholders	Annual workshop Final workshop	Y1, m11; Y2, m11; Y3, m11; Y4, m12. Y5,m7	Annual workshops were undertaken when annual meetings were run. Stakeholder meetings were regularly conducted by HAQDEC and Goroka-based staff, and by Maria Kwin Centre staff in remote areas. A final workshop could not be run due to disruptions at NFA (lockdowns), COVID-19 travel restrictions in PNG and from and to Australia, and HAQDEC-based staff unable to join in an online meeting. A workshop covering the findings of the project will be coordinated under the proposed project, most likely around a launch date. Nevertheless, the team has been, when able to travel close to their base, to communicate and apply the findings at farm sites and the satellite hatcheries that NFA has helped provinces and private operators to establish.
2.5	Train NFA and UniTech staff in social impact assessment skills	Training workshop following inception meeting Annual workshop	Y1,m1	Completed during the inception meeting, revisited at the SLA Workshop in October 2015 and revisited annually.

PC = partner country, A = Australia

Objective 3: To improve broodstock management, fingerling production and husbandry technologies

No.	Activity	Outputs/ milestones	Date Competed	Comments
3.1	Review of research outcomes of FIS/2008/023 and identification of research gaps	Written review report Group discussion on research gaps* Improved research strategy which will include revisions to risk measures**	Y1,m2 Y1,m1 Y1,m1 Y1 – to end of project (to include newly identified and emerging risks)	Completed – current research program has considered the outcomes of these activities and past projects. Completed – research gaps were the basis for proposed work on a new project. We note that between the end and start of the two ACIAR projects, NFA, UNSW and ANSTO continued to work on this component of the project and there was a refocus on capacity building using knowledge generated and other technologies available from Asia. NFA also invested in training of staff in hatchery techniques. Completed in Year 1, but regularly revisited to address new research questions. We note that COVID-19 impacts on our research program were successfully addressed by the project team due to the capacity building at UNSW, ANSTO and HAQDEC, and NFA's investment in training the staff. The team revised the research strategy annually and also adjusted at monthly meetings that were coordinated by the Project Manager. The Aquaculture and Inland Fisheries Unit took the lead in developing the research strategy as part of a strategic process at NFA. We will be assisting NFA with annual revisions of the strategy whether future work is funded or not as part of our long-term collaborative arrangements.

No.	Activity	Outputs/ milestones	Date Competed	Comments
3.2	Based on outcomes of the first activity, design and implement trials to synchronise spawning for hatchery and on-farm fingerling production	Syncronised spawning protocols Fingerling production trials	Y2,m9-Y3,m9 Y2,m9-Y3,m11 Y5,m2 (to include new methods of MT hormone use for farmers)	Completed with a focus on capacity building. The synchronised spawning trials revealed that the protocol is too difficult to apply. NFA funded the team to attend an AIT courser in monosex production and supported the upgrading of the hatchery. The team achieved > 99% all-male fish, which is a first for PNG. The success of the work has enabled HAQDEC to start distributing all-male fingerlings to farmers. This success is attributed to NFA's investment in training the team overseas. Completed. Fingerling production has improved, particularly after further training at AIT in Bangkok. Billy Kerowa established a new hatchery from NFA funds to support the research. Further renovation of facilities at HAQDEC, funded by NFA, will enhance hatchery production. We acknowledge that this activity was funded by NFA and included significant investment in renovations at HAQDEC to support the project and it's fingerling production program.
3.3	Compare and evaluate grow out and other husbandry practices	Research design meeting – design on-farm pilot trials* Secure trial ponds at HAQDEC Implement on-station, replicated trials at HAQDEC	Y1,m1 Y2,m1-m6 Y3,m1-Y4,m6 to Y5,m4	Completed but at HAQDEC due to social unrest in the community. The research concepts were reviewed regularly to take on board knew knowledge from the literature. There was a refocus to capacity building given the outcomes of FIS/2008/023. Husbandry practices were evaluated under Objective 4 because the main issues were related to fish feeding practices and monosex fingerlings produced under Objective 3 were used for the trials in Objective 4. NFA paid out EHP labourers that were problematic, but there are nonetheless risks to the safety of staff and further theft of fish. Risk measures were regularly revised. Final trials were delayed due to COVID-19 impacts on staff between February and June 2020. All work is now completed. The trials were successful due to the capacity building earlier in the project – undertaken at ANSTO, UNSW, HAQDEC and in the field in PNG.

No.	Activity	Outputs/ milestones	Date Competed	Comments
3.4	Compare methods for fingerling transport and stocking	Research design meeting* Implement trials on-station and on-farm	Y1,m1 Y2,m6-Y3,m11 to Y5,m4	Completed – only a simple design was necessary. This was largely undertaken by NFA under its satellite hatchery program that commenced in the final year of the project. Earlier trials were done at HAQDEC and with selected lead farmers eg Jacob Towa at Nebilyer valley who has become a major supplier of fingerlings.
3.5	Revise broodstock management and fingerling production and transport guidelines for tilapia from FIS/2008/023 using findings from the proposed research	Draft guidelines – and stakeholder workshop for farmers (training and feedback on guidelines) Finalise and publish guidelines	Y5,m3 Y5,m6	Delayed due to COVID – no workshop could be undertaken. Our stakeholder consultations also found that instructional videos were preferred. Joshua Noiney has published several videos on our project website. We have funding from the Crawford Fund and a Philanthropic source to produce more videos – underway. Nevertheless, written guidelines will still be produced as the remaining information from the project is reviewed by the team – also underway. Video-based guidelines are being produced by Joshua Noiney and Jes Sammut post-project under a Crawford Fund project and UNSW funding (philanthropy)
3.6	Train lead farmers and cooperative farmer groups on broodstock management, fingerling production and overall fish husbandry practices.	Training workshops in WHP, EHP and Morobe and at Maria Kwin Centre, DAL EHP and UniTech	Y3,m6 to Y5,m3	Although scheduled for Y3 onwards, the team initiated some training (basics of fish farming) following surveys at some sites where farmers were clearly in need of guidance. We continued to work with lead farmers from earlier project and the impact has been very noticeable with many of the lead farmers being responsible for improving farm yields in their communities. Three of these lead farmers (Jon Nekints, Moxy and Jacob Towa) were featured in our project video, Farming Fish for Change (see reference list for link).

Objective 4: To develop effective, low-cost feed formulations and feeding and fertiliser strategies

No.	Activity	Outputs/ milestones	Date Completed	Comments
4.1	Review research results of FIS/2008/023 and Justin Narimbi's Master of Philosophy research	Summary report of findings* Inception meeting presentation and focus group discussion	Y1,m1 Y1,m1	Completed Publication: Narimbi, J., Mazumder, D. and Sammut, J. (2018). Stable isotope analysis to quantify contributions of supplementary feed in Nile Tilapia *Oreochromis niloticus* (GIFT strain) aquaculture. *Aquaculture* 49 (5). 1866-1874.
4.2	Review and update feed ingredients database from FIS/2008/023	Collect sample from suppliers and other sources Submit samples to National Measurement Institute and UNSW for proximate analysis and to UNSW and ANSTO for isotopic analysis (under Activity 4.3)	Y1,m2 to end of project Y1,m2 to end of project	Completed. Inorganic fertiliser (NPK) was selected as key source of nutrients due to low N value of common crops in PNG. Samples were analysed in Australia.
4.3	Undertake proximate analysis for new ingredients	Data on proximate analysis Integration of data into feed formulations	Y1,m2 to Y5,m3 Y2,m10 to Y5,m3	UniTech withdrew from the project and this activity was transferred to UNSW and ANSTO. Despite COVID-19 restrictions, the project team completed all work. Sweet Potato and NPK were trialled in combination with supplementary formulated feed. Hindgut microbiomes were also studied to better understand the role of gut microbes in the breakdown and assimilation of nutrients. Lara Parata's PhD work, part funded by AINSE, added to this activity. NFA also funded Lara Parata's PhD research.

No.	Activity	Outputs/ milestones	Date Complete d	Comments
4.4	Conduct trials comparing growth performance of tilapia using different feed formulations, feed and fertiliser and fertiliser alone.	Staff training workshops – capacity building in experimental design and fish nutrition	Y1,m1 Y2,m10	Completed but we are continuing to offer training to the team in PNG to further build their research skills. The partnership between UNSW and NFA will be maintained regardless of funding. Jes Sammut and Angela Liu are developing instructional videos for the team, and also creating training materials that, if funded, will be used in a capacity building project.
		Experimental protocols	Y2,m10	Completed – we integrated standard methods with stable isotope and molecular methods for a more efficient research methodology. UNSW and ANSTO trained the project team in Australia. The team successfully implemented trials without supervision during the COVID-pandemic.
		Feed formulations and fertiliser dosages for experimental treatments	Y2,m3 to Y5,m4	Completed and papers under review with some under preparation. One paper (Parata et al., 2020) was published in open access.
4.5	Determine the contribution of specific feed ingredients to growth using isotopes.	Field trials using feed and fertiliser combinations under replication	Y2,m6 – on farm pilot trials	Fieldwork commenced in June 2018 in Eastern Highlands Province. Year 2 trials were delayed due to election year violence; the team focussed on SLifA surveys in safer provinces during this period. We compared feed, NPK and sweet potato and found that NPK led better growth performance. We also found that weekly feeding is sufficient to produce table sized fish if NPK is also used. This reduces waste and the cost of fish production.
		Analyse fish tissue, fertiliser, feed ingredients and potential natural food sources	Y3,m1 to Year 4,m6 Y5, m3 for on-station trials	Completed
		Peer-reviewed publications	Y2,m6-Y5,m8	2 manuscript were published (Parata et al, 2020; 2021). 2 are under review

No.	Activity	Outputs/ milestones	Date Completed	Comments
4.6	Conduct training on formulating feeds, producing feed, feeding and fertiliser strategies with lead farmers and farming cooperatives.	Workshops series in WHP, EHP and Morobe	Y2,m3- Year 5, m6	Workshops were conducted after surveys. NFA will continue to provide training via workshops after the project end date. Information will be integrated into Certificate level content at the Maria Kwin Centre,

7 Key results and discussion

7.1 Strengths, Weakness, Opportunities and Threats Analysis (SWOT) of inland aquaculture and PEEST Analysis – Objectives 1 and 2

7.1.1 PEEST summary

This section is a summary of the PEEST analysis with full details presented in Vira and Pandihau (2020) which is being revised post project to address changes to government policies and NFA's corporate planning.

Aquaculture is currently established and recognised as a contributor to food security, income generation and rural development in PNG by various Government development strategies. In recent years the number of stakeholders involved in production, research, development, extension and training has grown, and there is a greater interest in fish farming by NGOs and the mining industry to provide food production opportunities in rural communities. There is now a greater push by NFA to understand external factors influencing the sector in order to enable stakeholders to properly plan interventions to reduce perceived threats and increase opportunities for growth of the industry. The main findings of the PEEST Analysis include:

- The government policies and legislation relating to aquaculture are generally supportive and create a solid basis for the promotion of the activity for food security and wealth creation. There are areas that require attention such as strategic development plans and updating policies, which is now underway as a result of a revised NFA Corporate Plan and the submission of a strategy by the Aquaculture and Inland Fisheries Unit.
- Current focus should be on small-scale farming except for cage-based farming which has the greatest potential for commercialisation. Nevertheless, research on nutrition for higher intensity, pond-based farming is recommended.
- Aquaculture addresses food security and is able to create income-earning opportunities in rural areas but not at a commercial scale for most farmers. Government policy to reinvest income from the non-renewable to the renewable sector provides an opportunity to grow the industry; however, our SWOT Analysis and other research has shown that infrastructure is a major impediment to commercial scale production except for limited peri-urban farmers and reservoir-based farmers that have access to road networks and farm inputs.
- Little work has been done on the environmental impact of aquaculture in PNG. There are environmental regulations in place to govern the activity but the small scale of most of the farms negates their requirement for a permit to operate. The combined effect of many small farms on a river system or the impacts of cage culture on a reservoir are areas requiring investigation and will be addressed in a follow-on pipeline project if funded by ACIAR. UNSW has invested in EIA training and will continue to provide support to NFA beyond this project as part of the long-term collaboration between the two agencies.
- The high population growth in PNG is not being matched by employment opportunities and services resulting in increased social problems. These problems are primarily urban but are now spreading into rural areas. Aquaculture's ability to fit the rural lifestyle is the main reason for its acceptance; however, it is not immune to social problems of stealing and vandalism. Nevertheless, it has

contributed to the cessation of tribal fighting and has been linked to reduced crime rates.

- The introduction of farmers and extension officers training was a key enabling factor for the acceptance of aquaculture. Other technological advances such as the introduction of GIFT and cage culture have further strengthened the growth of fish farming. There is still a need to improve capacity and numbers of trained personnel as well as the functionality of key institutions.
- Environmental conditions are highly suitable for small-scale fish farming, and ponds integrate well with cropping; nutrients from ponds are utilised by vegetable crops and rarely enter waterways.
- Compared to fish farming in other countries, technologies are not readily available, although it was found that our project technologies could be adopted by farmers.

7.1.2 SWOT Analysis Findings

Strengths and weaknesses

The strengths and weaknesses are largely internal factors that affect the sustainability of the industry (Table 2). The tradition of farming is a key strength in PNG, despite the differences between growing fish and farming vegetable. The concept of producing your own food is integral to subsistence farming in PNG and has helped farmers to adopt fish farming as a companion practice, mainly to address dietary protein deficiencies (Vira, 2015; Sammut *et al.*, 2021a). Although this is a strength, a related weakness is a poor understanding that fish, unlike vegetables, require a different skillset and more investment in husbandry to maximise yields (Tong, 2018; Vira, 2015). The role of woman in fish farming is also often unacknowledged. Women farmers noted that they are more likely to care for fish because they are responsible for preparing food for the family and less likely to risk a fish crop through negligence. However, through NFA and project-based training, men and women in our area of activity had become ‘partners in fish farming’. Women commented that men had become more engaged in fish farming once trained and after successful crops were achieved.

Fish farming success depends on a supply of quality fingerlings, good fish feeding strategies, managing stock to reduce in-pond breeding, and maintaining good water quality. Farmers with a poor understanding of fingerling quality are likely to stock their ponds with stunted adult fish purchased at markets and passed off as fingerlings by unscrupulous sellers; this was consistent with the findings from our previous project, FIS/2008/023. The causes of stunting in fish include poor nutrition as a result of low-quality or expired feed, and poor feeding strategies, environmental stress affecting appetite, or increased competition for feed due to farmers not removing the progeny of adult fish in ponds. Farmers report that ponds are overcrowded with progeny resulting from uncontrolled breeding (Hiruy and Sammut, 2021; Vira, 2015) but they are unable to distinguish which fish are stunted and which were recently stocked fingerlings. Stunting can also occur if fish divert energy away from muscle growth to meet reproductive energy demands.

The high cost and poor access to quality formulated feeds is a major bottleneck to growth of the industry and a cause for poor farm yields. This was the premise for Objective 4 of this project, and remained an issue because farm numbers had increased and supplied of feed decreased due to diversion of feed and raw ingredients to other types of farming. Fish feed accounts for more than half the production cost (El-Sayed, 1999) and in PNG can be upwards of 70% if farmers feed their stock daily due to higher feed costs compared to other countries (Hiruy and Sammut, 2021). Interviewed farmers complained that fish feed, when available, was too expensive, or that they had no understanding of the feeding frequency required to maximise their yields. Many farmers also do not keep records to determine their input and production costs, thus being unable to determine if fish farming is profitable. For subsistence farmers, producing fish for the household is not problematic since many do not depend on a high fish feed input, and fish of any size are considered edible. Nevertheless, increasing the size of farmed fish and improving farming efficiency can enable farmers to also sell excess fish after household protein needs are met. Our data suggests that up to 40% of excess fish are shared with others in the community, thus making protein more accessible. However, farmers who produce fish primarily for income are impacted by the high cost and low availability of fish feed in PNG, and this can lead to farm abandonment, which was also found by Vira (2015). This is particularly the case for cage-based farmers who depend entirely on formulated fish to growth their fish. By contrast, small-scale, pond-based fish farmers utilise natural food (eg insects and algae), fertiliser to enhance primary production, and vegetables or crop waste to supplement the diets of farmed fish (Narimbi *et al.*, 2018; Parata *et al.*, 2020). Later we discuss the findings of our trials on fertiliser.

The lack of road infrastructure in PNG, along with limited cold storage facilities and cold transport services, limits the distribution of fish from farming areas to markets (Hiruy and Sammut, 2021; Vira, 2015). Consequently, farmers who are not located close to a major highway, or without access to cold storage, cannot sell fish to the more lucrative markets in urban areas. Regardless, transport costs in PNG are also high and a disincentive to small-scale farmers with low financial capital to distribute their fish more widely. NFA staff advised that advancing farmers to larger scale operations will be difficult until PNG's road infrastructure is improved. Cage-based farming has greater opportunity because it takes place in reservoirs that have roads that connect to the main (but limited) road network.

Support from members of the farmers' wantok system is a key strength given that the high cost of labour associated with constructing farms is addressed by kin contributing to pond building and construction of water supply infrastructure (Sammut *et al.*, 2021a; Tong, 2018; Vira, 2015). The wantok system is based on reciprocity and has enabled our various projects to build knowledge chains with lead farmers as nodes where wantoks intersect. Wantok translates to 'one language' or applied to people who speak the same dialect' but can also be used to describe people of common kinship, social or religious groups, or ethnic identity (de Renzio, 2000). Generally, it is a network of relationships and behaviours, and also a key source of social capital (Reilly, 2001). Social capital under the wantok system enables farmers to reach agreements on water resource sharing, which is critical to farmers who do not own land adjacent to a permanent water supply. Under the wantok system, farmers have built pipelines to transfer water to their kin, and in keeping with the spirit of reciprocity, the beneficiaries of shared water provide labour and other support to their wantoks. Fish farming was also found to link wantoks, thus increasing access to social capital. Farmers have also reported that under the wantok system, excess fish are shared, often to honour informal debt for assistance with pond construction and water sharing. This has facilitated better access to protein to wantok members who do not farm fish or livestock, and has also fostered interest to eat and farm fish (Joe Alois, NFA, personal communication; Hiruy and Sammut, 2021).

Opportunities and Threats

Opportunities listed in Table 2 are currently being explored or are being integrated into NFA's strategic planning for inland aquaculture development. The growth of the industry has had a commensurate increased interest in farming as well as recognition, by government, of the value of fish farming to meeting the protein needs of people. This is reflected in the PNG Government's various development strategies (eg recent amendment for the Fisheries Management Act to include aquaculture in its objectives). NFA's Aquaculture and Inland Fisheries Unit is also investing more in the production of quality fingerlings and providing farmers with subsidised feed whilst efforts are underway to improve commercial supply of fish feed. For example, NFA is establishing satellite hatcheries through partnerships with provincial governments and farmers to overcome lack of fingerling supply that has, until recently, been limiting growth of the industry. Until this program was established, farmers relied on HAQDEC, which could not meet the demand for fingerlings, and advanced farmers, who are not always able to deliver fingerlings to other provinces. In partnership with our ACIAR-funded projects, NFA is also investing more in farmer training programs for extension staff and farmers, and transferring technical knowledge from our projects to formal training programs at universities, colleges and training centres.

In recent years, advanced pond-based farmers and local entrepreneurs have been responsible for the surge in cage-based farming, utilising the water resources of artificial reservoirs. With support from NFA and an SPC project, farmers have developed business plans and have been provided business start-up support. Our program of research is expanding to tackle the bottlenecks for cage-based farming, mainly to address fish nutrition challenges, and to determine the carrying capacity of reservoirs and develop better management practices to meet economic and environmental goals. To date there are no guidelines for cage-based farming in the PNG context, thus we are shifting some of our research focus towards developing better management practices that minimise environmental impacts and maximise fish production. Similarly, we are working with NFA to develop better decision-making processes so that the cage-based industry grows sustainably and does not cause environmental degradation, as has occurred elsewhere in the world. UNSW and ANSTO is also planning to build capacity in lake modelling if a follow-on project is supported, and by other means if necessary. PNG is at the start of cage-based farming and needs to avoid the environmental and production disasters that have occurred in other countries.

Many of the raw ingredients for fish feed are utilised for other livestock (Glatz, 2012; Glatz et al, 2013). The lack of affordable fish feed has been temporarily addressed by NFA importing feed from Vietnam and subsidising the cost for farmers. This approach is considered a short-term intervention. Accordingly, NFA is developing strategies, in partnership with our planned follow-on ACIAR-funded project, to facilitate local feed production and to reduce the cost of feed ingredients for commercial and farm-based milling of pellets. This will link to a planned DFAT project on addressing livestock feed supply issues in PNG. The research is entering a new phase that involves breaking the dependency on imported feeds and to utilise alternative, locally-sourced feed ingredients for medium-scale, pond-based farming and cage-based production, and strategies to improve natural food production for small-scale farms.

Theft of fish is prevalent in PNG and a major reported threat. Farmers often report that entire crops are stolen usually as they near harvest size. Farmers are building new houses closer to their ponds to monitor their crops (Vira, 2015) but fencing to secure farms is too expensive for small-scale farmers. FIS/2008/023 had all fish stolen at HAQDEC and was fortunate to resurrect two families via lead farmer networks and wild stock from Yonki Reservoir. Jealousy can often lead to sabotage, such as poisoning fish crops with plant-based toxins or chemicals. Early in our program, trout farms in EHP were affected by regular sabotage of stock to the point that some farms ceased to operate. Such events are also blamed on sorcery leading to tribal fighting (Sister Pauline Kagl, Sisters of Notre Dame, personal communication). On one hand, tribal fighting, which is commonplace in PNG (Reilly, 2008), can lead to destruction of farming infrastructure, prevent farmers from accessing their ponds and also impact technical support for farmers due to risk to extension staff. On the other hand, fish farming has also helped to reduce or end tribal conflicts in the highlands of PNG by bringing tribal fighters together to share resources and build ponds (Hiruy and Sammut, 2021; Vira, 2015).

The genetic robustness of tilapia in PNG is also a threat, but yet to be investigated (Vira, 2015). GIFT is the most widely farmed tilapia strain in PNG and all GIFT can be sourced to nine fish that were imported in 1999 by a JICA project. The extent to which inbreeding has affected the genetic robustness and the growth and reproductive performance of GIFT is unknown but nonetheless considered a threat by NFA (Vira, 2015). Interestingly, fast growing and larger GIFT are reported from the Fly River in Western Province, and we postulate that tilapia farmed on the Indonesian side of New Guinea could have contributed to the genetic profile of fish in this system via escapes or translocation by fish farmers who regularly cross the border. Alternatively, accelerated natural selection of fast-growing GIFT may have occurred. Plans by NFA to introduce new GIFT broodstock from Asia are currently deferred due to the risk of introducing Tilapia Lake Virus (TiLV) which has devastated tilapia farming in other countries. Nevertheless, there is risk of TiLV entering PNG from Indonesia (currently TiLV free), most likely via the Fly River in Western Province where a section of the river forms part of the border. There is currently no biosecurity plan to address this risk in PNG. NFA has established a quarantine area at HAQDEC in preparation for the introduction of Fly River broodstock.

Table 2. Summary of SWOT Analysis findings (Sammut *et al.*, 202a) for inland fish farming based on a synthesis of information from Hiruy and Sammut (2021), ACIAR Project FIS/2014/062, Vira (2015) and Tong (2018)

Strengths	**Opportunities**
Tradition of growing food Ability to integrate fishponds into vegetable gardens High social capital to build ponds and share water resources via the wantok systems Good soils for earthen ponds Some provinces have consistent rainfall National Fisheries Authority commitment to developing the industry History of donor interventions Established knowledge networks and wantok system as a source of social capital	Growing demand for fish Utilisation of reservoirs for cage-based farming Integration of fish farming into school and university programs Scaling up of advanced farmers to create demand for local feed production Creation of a local feed production industry to reduce feed costs Model farms in provinces to educate farmers Expansion of satellite hatcheries Farmers have developed trust through working with research and extension agencies Farmers demonstrated eagerness to learn better management practices Potential for a retail market and fish processing business Further development of knowledge networks using social systems and improved government support services.
Weaknesses	**Threats**
Lack of financial assets to scale up production systems Lack of business acumen in farming community Poor access to fish feed and raw ingredients High cost of fish feed Poor fish husbandry skills Lack of a market chain	Introduced fish diseases, particularly the threat of Tilapia Lake Virus entering PNG via Indonesia Climate change Droughts and floods Theft of fish Sabotage due to rivalry and jealousy Competition for raw ingredients for fish feed Escalating feed costs

Lack cold storage and cold transport in remote areas Inadequate road infrastructure to transport inputs and farm outputs Lack of postharvest skills Remote farmers have limited access to technical support Limited supply of aquaculture inputs Outdates development strategies for inland aquaculture Reduced funding to NFA due the 90/10 Act.	Interruption to production and destruction of ponds and water supply due to tribal wars Genetic quality of GIFT in PNG Long-term reduced funding to NFA and other government agencies

7.2 Sustainable Livelihoods and Lifestyle Analysis Findings

7.2.1 The demography of small-scale fish farmers in PNG

The survey questionnaire was designed to solicit basic demographic characteristics of fish farming households, and we surveyed 686 households in seven provinces (8 including Tong, 2018). The median age of fish farming household heads was 40, and the median age of their spouses was 36. The average family size of fish farmers is 5, which is lower than the national average family size (6.2 persons per household) (PNG National Statistics Office, 2011). However, when farmers were asked to name household members involved in fish farming, the average number of people involved was around 8. The figure is more than the average household number. Although this can be considered as an error of record and data handling, it seems that farmers have included their Wantoks – relatives and community members who might have been involved in the fish farm contributing labour, particularly during the initial pond digging stage in these figures. As we will see later, the traditional Wantok system influences how resources are allocated, and products are distributed. The survey results also indicated that the majority of household members, including children, are engaged in fish farming. It implies that in PNG, fish farming is a family-friendly endeavour and that those involved in fish farming are at their most productive age.

Overall, the majority (99%) of fish farmers surveyed (n=680) were male-headed households, while only 1% (n=6) were female-headed households. As the districts for this survey were selected randomly, and a purposive sample was set for each locality, the type of farmers surveyed can be considered representatives of the estimated 60,000 fish farmers in PNG. Given this, the proportion of male-headed households in fish farmers seem higher than the national average, which is 88% (PNG National Statistics Office, 2011).

As indicated in Table 3 below, although fish farming is not the primary occupation of the majority of household (being a primary occupation only for 25% of household heads and 5% of their spouses), the data indicated that 82% of household heads and 52% of spouses considered fish farming as either their primary, secondary or tertiary occupation.

Table 3*: The relative position of fish farming as an occupation among farmers surveyed*

	Household heads		Spouses (all female)	
Occupation	Count	percentage	Count	Percentage

Primary	196	28%	31	5%
Secondary	183	27%	95	14%
Tertiary	189	27%	227	33%
Total	568	82%	353	52%

The fact that 99% of fish farming households are male-headed, and that 82% of this male household heads considered fish farming as one of their occupations, may obscure female participation. However, a closer look at the response regarding the occupation of spouses reveal that women are highly involved in fish farming in PNG, with 52% claiming fish farming to be their primary, secondary and tertiary occupation. Interviews also confirm that women are highly involved in the day-to-day activities of fish farming at the household level. This seems to be consistent with the generally-held notion that women in PNG are highly involved in household farming activities that require daily husbandry and regular sale of products such as vegetable and fish farming (Mikhailovich, Pamphilon, Chambers, Simeon, and Zapata, 2016).

The survey results (see Table 4) also established that 67% of the fish farmers surveyed had a minimum of primary school education. As Table 2 indicates, 4% had a high school qualification, and 6% had technical and university degree. Overall, the seven Provinces seem to have similar demographics. However, compared with other provinces, farmers surveyed in Simbu had a high-level education, with 17% of those surveyed with secondary and tertiary education, while a relatively higher proportion of household heads in WHP had lower education levels with 40% of those surveyed with no formal education.

Table 4: Level of education of HH heads by Province

Provinces	WHP		Jiwaka		Simbu		EHP		Madang		Manus		Morobe		**Total**
Level of Education	#	%	#	%	#	%	#	%	#	%	#	%	#	%	%
No formal education	39	40%	27	24%	18	18%	29	25%	19	25%	6	7%	19	20%	**23%**
Primary (Gr.1-Gr.6)	34	35%	45	41%	30	30%	44	39%	36	47%	46	51%	40	41%	**40%**
Middle (Gr.7-Gr.10)	19	19%	32	29%	35	35%	30	26%	12	16%	31	34%	29	30%	**27%**
Secondary (Gr.11-Gr.12)	1	1%	3	3%	5	**5%**	4	4%	3	4%	5	6%	4	4%	**4%**
Tertiary/Higher	5	5%	4	4%	12	**12%**	7	6%	6	8%	2	2%	5	5%	**6%**
Total	**98**		**111**		**100**		**114**		**76**		**90**		**97**		**100%**

7.2.2 Household assets and the impact of fish farming on participating households

As noted earlier, the SLifA framework recognises five household assets: Natural, Human, Financial/Economic, Physical and Social capitals. These assets (capitals) underpin livelihood at the individual, household or community level. It is also important to note that these assets are interdependent at the household level. In other words, there is a relationship between these assets, and this can be different across communities and even households. For example, a household may have secured access to land (natural capital), but the same household can have poor access to human and social capital. In other cases, a household may have the human and natural capital it needs but faces difficulty accessing the financial capital required to utilise or develop its assets.

It is also important to note that the availability of one asset can affect access to other resources. For example, if a household has secure access to land (natural capital), their ability to access financial capital can be enhanced if they can use the land as collateral to obtain loans. Thus, in this section, we will try to explore the impact of the research for development in inland aquaculture on the livelihood participating household both by assessing the basic assets they have and the relationship between these assets at the household level.

7.2.3 The stock of knowledge of fish farming and its interaction with human and social assets among surveyed fish farmers

One of the main aims of the inland aquaculture projects was, and still is, to support farmers' access to high-quality protein and income-generation through fish farming by producing relevant techno-scientific knowledge. Survey results indicate that the inland aquaculture projects have provided opportunities for knowledge sharing and transfer, which seem to have had an impact on both the human and social assets of participating populations (see Lynch *et al.*, 2016). However, the utilisation and effect of this technical knowledge, particularly on traditional communities with strong kinship and tribal bonds, such as in PNG, is also dependant on current human capital and socio-cultural values of these communities, among others (Curry *et al*., 2015).

The knowledge, skills, education level, good health, interpersonal skills, and ability of a household to labour is known to have a significant influence on the capacity of households to pursue a certain livelihood strategy and achieve their livelihood objectives (Sayer and Campbell, 2004). Perhaps, that is why human capital is seen as a keystone within the SLifA. However, it should be noted that the social dynamics in the community also plays a crucial role in determining the way technical knowledge is perceived and existing human capital is utilised at the household level (Diedrich, Benham, Pandihau and Sheaves, 2019). The availability of social capital depends on the ability of household members to socialise with other people; either through ethnic, traditional and local organisations or social groups or class. In this regard, the survey results indicated that the traditional reciprocity system, ie the 'Wantok system' and other religious and cultural networks played a significant role in determining the livelihood strategies pursued.

These socio-cultural and religious networks also provided a way of escaping shocks such as the death of a loved one or a natural disaster. Over 73% of households surveyed indicated that they had a membership of ethnic, traditional and local organisations that included normative institutional membership of Churches, development associations farming cooperatives and youth groups. These institutions were considered to be useful by participants in maintaining unity and community relationships, creating a support structure for community members to help each other and in maintaining cultural norms and enforcing law and order in the community. However, the strongest values and influence were attributed by many participants to came from informal, traditional norms such as ethnic, religious, and kinship networks such as Wantok relationships. These were influential not only in attaining physical resources such as land but also in mobilising both human and financial resources for the household to pursue its livelihood strategies and attain its livelihood outcomes.

Although the Wantok system is usually a reciprocity association or relationship forged mainly along with kinship and tribal lines, there are also Wantoks whose association is based on childhood or professional acquaintances, religious and other affiliations, although these associations may not be as strong as those formed along ethnic lines. As de Renzio (2000, p. 21) notes, Wantok refers to a system of relationships or set of obligations between individuals with a common language (where the wantok “one talk’ is driven from), kinship, locality (origin), and other social and religious associations. However, these associations can be both instruments of inclusion and exclusion at the same time. While Wantok can act both as a social welfare support system benefiting members of a community, such a benefit, could, in some cases, be at the cost of others losing as the Wantok system can encourage nepotism.

Farmers were asked to name and discuss factors that encouraged them to pursue their livelihood strategy and achieve their livelihood outcomes, and Wantok system was mentioned both negatively and positively, perhaps indicating whether the household was at the receiving end or the losing end of the benefits from one's Wantoks. Some participants indicated that they were able to capitalise their socio-cultural relationships to improve their livelihood. Local researchers/field workers also noted that across PNG, there is a strong mutual support system based on ethnic and kinship allegiances or Wantok system. While many have mentioned the Wantok system in a positive light, others have also mentioned that the Wantok system had created a system of nepotism in the country and has the potential to exclude a group of people from achieving their livelihood needs. As an informal social structure, it is also important to note that the Wantok system could undermine and to a certain extent override existing formal institutional arrangements set-up to enforce the law and distribute public good and services (Nanau, 2011).

Although it is beyond this project to explore the nature of Wantok and how it works concerning the livelihood of fish farming communities in PNG, it was apparent that it had an impact on farmers capacity to mobilise land, human and capital resources to pursue their livelihood strategies. Some reported that they were able to use communal land for fish farming by using their social status and relationship with their Wantoks. They also noted that the Wantok system encourages them to share fish resources and help pay some fees, including school fees for their Wantoks when the need arises as a way of reciprocating the favour other Wantoks had shown them.

The survey results indicated that the education level of fish farmers surveyed was not significantly different from the national average (PNG National Statistics Office, 2011). However, a simple look at the data seems to indicate that fish farmers with a higher level of education had better farms both in terms of size and productivity, although it was not possible to establish this statistically. There was no significant correlation between education level and the productivity of the farms. However, as can be assumed, the likelihood of better-educated farmers adopting new technology and innovating new techniques can be high. It is also possible that these farmers can act as critical links in the information and knowledge networks between researchers and farming communities as early adopters and may facilitate the scaling up of farming. Thus, the level of education, skills, knowledge and leadership capability of a person in a household can have long-lasting effects on individuals and the community, although its impact may differ from one household to the other. The impact of education and leadership on the livelihood strategies pursued the outcomes attained can be different for different household based on the household size, level of education, experience, age and gender profiles and socio-cultural values (Curry *et al.*, 2015; Morse, McNamara and Acholo, 2009).

7.2.4 The stock of natural and physical capital of fish farmers

One of the determining assets for fish farming is access to natural resources such as productive land and water. Physical capital such as fish broodstock, fisheries implements and machinery, can also support a household to achieve its livelihood goals. Physical capital also includes shared infrastructure such as road, water supply and communication (Lax and Krug, 2013). The availability and affordability of infrastructure components such as transport, water supply and sanitation, energy and information contribute to the livelihood of households positively. On the other hand, if some of these infrastructures are poor or non-existent, a household may struggle to achieve its livelihood objectives. The household may find it difficult to take its products to market. Nevertheless, the goal of addressing the immediate protein needs of a family or a village can be met.

In analysing available land and the physical assets that participating farmers had, we have considered each household's resource use for other farming activities and neighbouring households. It is important to note that land and the physical assets available for households can be used for multiple activities. There is also an element of communal use in water and other infrastructure.

7.2.5 Accessibility of farms, water infrastructure and communal resources

More than 55% of the households indicated that they owned or had access to land other than their immediate farmland. These other properties were described as rainforest, river and grassland in the main. The nature of access rights to land was described as communal land ownership rights or customary land property rights that were considered as traditional land right passed from generation to generation.

The survey results show that 76% of the farms are accessible by car, and the average distance from the main road is less than 5 km. However, most main roads were not navigable particularly in wet periods, and most farmers did not own a car or truck. Walking 5km and carrying farm inputs or product was also a deterrent. More than half of the farmers surveyed (52%) indicated that their primary sources of drinking water are rivers and streams, while over 30% of households reported having access to piped water infrastructure that was mainly controlled by the local community. This is much higher than the national average for rural areas, which is 13.6% for male-headed households (PNG National Statistics Office, 2011). The main sources of electricity and energy for the surveyed households were mini hydro (30%), electricity grid (30%), and generator (30%). The source of electricity was higher than the national average on all counts (PNG National Statistics Office, 2011).

Overall the majority of surveyed households in the seven Provinces had traditional thatched roofed houses, and only less than 10% of households had corrugated iron-sheet roofed houses. The proportion of homes with corrugated metal sheets seems lower than the national average of 29.5% for rural households (PNG National Statistics Office, 2011). The average home size was between 46 and 50-meter squares. Moreover, only 2% of households reported having toilets inside the house structure, and the rest reported having a toilet outside the house, which is consistent with the national average.

7.2.6 Aquaculture and other farming assets

Table 5, 6 and 7 show some of the assets owned by surveyed farmers. The average reported farm size was 3 ha, (on average 40% was allocated to crops, 35% to fruit trees, 20% to vegetables and the remaining for other purposes). The main farm animals owned by fish farmers included fish, pigs, goats, and cattle.

Table 5. Aquaculture and other farming assets owned by fish farming HHs in WHP

Assets	No. of HHs reported	The proportion of ownership as a percentage of fish farming HHs surveyed (686)
Motor pump	13	2%
Hand nets	77	11%
Cages	45	7%
Cooler box	90	13%
Chainsaw	85	12%
Handmill	3	Less than 1%

Table 6. Livestock and other farm animal ownership by fish farming HHs by Province

Provinces	WHP		Jiwaka		Simbu		EHP		Madang		Manus		Morobe	
	# HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH
Fish	72	1218	83	3835	89	5038	96	3541	71	1019	56	706	93	1423
Pigs	74	6	71	5	67	5	51	3	50	3	24	2	50	4
Shoats	13	3	4	5	3	5	28	5			1	2	1	1
Cattle	2	2	2	5	2	5	3	3					2	2

Table 7. Other assets owned by fish farming HHs by Province

Provinces	**WHP**		**Jiwaka**		**Chimbu**		**EHP**		**Madang**		**Manus**		**Morobe**	
Other Assets	# HHs reported	Ave./ per HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH	No. of HHs reported	Ave./ per reporting HH
Cars	3	1	16	1	9	1.4	10	1	3	1	2	1	3	1
Motorcycle	1	1	2	1	0	0			1	1	4	1	1	1
Bicycle	6	2	10	1	10	1.5	7	1	8	1	1	1	19	1
Tractor	0	0	2	1	1	1								
TV	9	1	19	2	29	1.4	33	1	8	1	8	1	13	1
Radio	22	1	29	3	40	1.5	37	1	27	1	15	21	26	1
Stove	9	1	9	2	12	1.3	9	1	2	1	1	1	7	1
Generator	20	1	26	1	25	1.5	35	1	16	1	10	1	28	1
Solar Panel			13	1	18	1	10	1	32	1	9	1	4	1
Coffee Pulper			12	1	17	1	12	1	1	1	1	1		

7.2.7 The nature of fish farming

Tilapia and carp were the main farmed fish species with only five farmers reporting farming rainbow trout and one farmer reported farming eels. The two main reasons for farming fish among households surveyed were:

- Home consumption and nutrition - food security; and
- Income generation.

The average number of ponds per HH was reported to be 9, and the average number of stocked ponds per household was seven ponds. The average pond size was 60 m^2. The survey results indicate that 83% of the household farms use feed supply. While 51% of the HHs feed their fish daily (once, twice and three times a day), 10% fed once a week, 7% fed two to four times a week and the rest did not have regular feeding frequency. The feed used by households included: pig manure, chicken manure, kitchen waste, vegetables – t broccoli, potatoes, garden waste, rice, fruit leftovers, fishmeal, earthworm, cassava and cocoa.

The survey results indicate that fish farmers were selling a reasonable amount of fish continuously throughout the year, although a reasonable amount of fish was also given to neighbours and relatives. The establishment of inland fish farms among communities both in the highlands and coastal areas of PNG has expanded access to protein-rich food resources and financial resources from fish sales both for immediate livelihood needs and for lifestyle purposes (see also Simard, Militz, Kinch, and Southgate, 2019). When asked whether they had sold fish before the survey was conducted, 41% of the households reported that they had sold table size within three months before the survey date. The main markets for their fish included: provincial markets, local community markets, roadsides and supermarkets. The average size of fish sold is reported to be 300-400 grams and 20 – 25 cms. The average number of fish per harvest per household that reported harvest was 50 fish, although there were some outliers with farmers reporting as many as 300 fish harvested. The reported average price of table size fish ranged from PGK 5 to PGK 25.

Although the majority of fish were consumed at home, 20% of households reported that they had given fish to their neighbours, relatives and Wantoks, and the average number of fish given away per household in the quarter was 20 fish. This is an important point in light of both food security and the implications of reciprocity in the Wantok system. Although the productivity of fish may not be considered high, in terms of attaining food security distributing fish to neighbours play a significant role.

External technologies that fish farmers reported to have used included: use of PVC pipes in fish ponds, use of nets, new breeding skills, fish feed and integrated farming (fish and duck farming). However, 95% of households reported that they would like additional skills in fish farming and some of the suggested training they would like to receive include training in breeding skills, feed formulation, feeding strategies and pond management (this falls within the scope of the ACIAR project).

7.2.8 The financial capital of fish farmers in PNG

Financial capital is a crucial enabler for the livelihood of a household. A household that has access to financial capital is better placed to attain its livelihood goals, as it can afford to pay for services and goods that are necessary to achieve its objectives. Having access to financial assets enables the household to pay for buying enough food, paying doctors' fees, sending family members to school and buying machinery.

Households were asked to list their income and expenses, and they reported that the average income per household per quarter (three months) was PGK 2, 477.00 and the average cost per household was PGK 1, 857.00. The figures seem reasonable, although it is possible that households have under-reported income.

The primary financial institutions used by households include banks, microbanks and private lenders. Household savings mainly finance fish farming.

7.2.9 Vulnerability context

Trends, shocks, and seasonality often have a direct impact on people's assets and livelihood options. One of the significant changes that households reported was the population increase. Over 90% of households reported that there was a substantial human population increase in their communities in the last decade, and nearly 70% thought that there was a decrease in the productivity of their farms during the same period. Farmers have also observed that there was a change in rainfall patterns in the last decade. Over 60% reported that there had been changes in rainfall patterns in their area; they particularly noted regular long dry spell and seasonal floodings. Over 60% also noted that other changes affected their livelihood included deteriorating road conditions, increased cost of living, and increased alcohol and drug abuse, particularly among young people. These changes are likely to affect the livelihood of farmers, including fish farming and erode gains made in increasing the availability of high-quality protein at the households level.

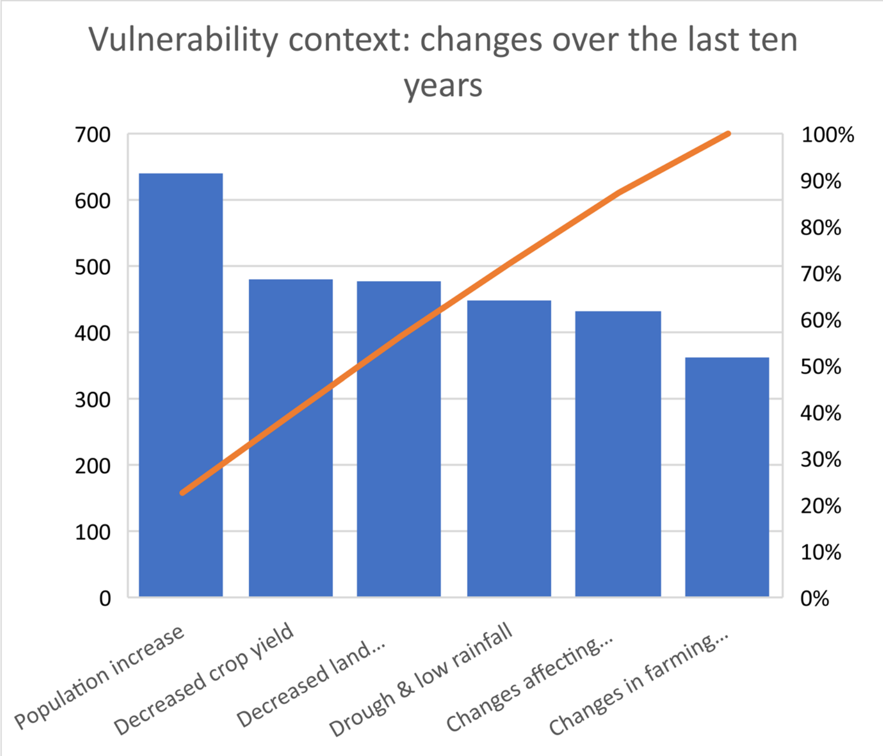

Figure 3. Vulnerability context: changes in the last ten years

Our survey results also showed that 24% (n=166) of the households surveyed recognised resource conflict as an existing issue in their communities, and 22% (n=151) reported having witnessed an ethnic conflict in their area in the last ten years. Many of these participants, reported to have been affected by these conflicts personally and named the sources of conflict witnessed to be land disputes (with clan members), tribal/ethnic fighting, and water use related issues. However, the majority of those who reported having witnessed ethnic conflict (83%) indicated that ethnic conflict has been on the decline.

In the literature, there is an indication that inland aquaculture can lead to conflict, particularly between different jurisdictions over access, control, and harvest of fish (e.g., Salayo, Viswanathan, Ahmed, and Garces, 2006). To the contrary, the survey results indicated the PNG experience to be different. Our data indicated that inland aquaculture in PNG has been instrumental in peace-making by providing the opportunity for communities to work together, share resources and foster cooperation and knowledge transfer as people recognise the benefits of fish farming (Lynch *et al.*, 2016). Participants claimed that fish farming was instrumental in bringing communities together and resolve some issues both by creating opportunities for young people to engage in farming continuously and by creating a source of income and a way to share resources among neighbours. The fact that over 20% of fish farmers were giving nearly 40% of their fish harvest to their neighbours also reinforces the idea that fish farming can act as peace-making venture by way of sharing resources. During the life of the project, at least three tribal wars have ended due to fish farming bringing adversaries together, and the ACIAR team was integral to the success of this via training and mentoring of farmers. Other social conflicts have also been reduced as a result of the project's interaction with the farming communities and training lead farmers who have gone onto leading rival tribes to farm cooperatively.

7.2.10 Policies, Institutions and Processes

It is understood that policies, institutions and processes influence access to assets and technology, livelihood options, and coping strategies as well as key services. PIP can increase or decrease livelihood vulnerability, narrow or widen livelihood options. Assets can also be created through government policy to invest in infrastructure (physical capital), education (human capital), and local institutions (social capital). Formal and informal institutions facilitate access to resources that affect the livelihood of a household. Therefore, understanding social relationships and power dynamics embedded in institutions and other structures and processes is vital to comprehend the livelihood of a household (Krantz, 2001; Scoones, 1998)

When participants were asked to discuss government policies, institutions and policies that affect fish farming, many were unable to articulate the current policies, institutional arrangements or process that are in place. However, there was awareness that the ACIAR/NFA-funded inland aquaculture projects and other partner organisations such as the Maria Kwin Centre provided information and training and that government agencies were providing certain assistance in the form of grants to fish farmers (eg Project Development Funds from NFA). Some also mentioned that they were informed about possible assistance through politicians (local members of parliament).

For this reason, it seems that the opportunity and capacity of fish farmers to access services and available opportunities varied based on their knowledge and accessibility to main service centres such as provincial offices. Thus, although it is apparent that there are existing policies, and institutional arrangement and processes set-up by the government and NFA, in particular, to support farmers, the effects on the livelihood of each household are different. This is partly due to the differences in the asset bases and the strengths and weaknesses of each household. However, it is also possible that certain households are missing on certain opportunities because of a lack of awareness of what is available to them.

7.2.11 Livelihood Strategies and outcomes pursued

In analysing the livelihood strategies of farmers surveyed, the focus was on understanding households' strategies related to inland aquaculture and related food security activities. Understanding the factors behind the strategy adopted by the household was the centre of our analysis (Scoones, 1998). From the results, the primary livelihood strategy for fish farming for over 90% of household surveyed was to produce fish for home consumption and income generation. For the rest of households (less than 10%), income generation, expanding and commercialising fish farms, building a new house, and wedding children were mentioned as primary strategies, while a few mentioned the availability of government funding and the encouragement by their neighbours to be the prime drive for them to start fish farming.

Although the majority of households indicated that food consumption and income generation were the primary strategies, it is possible for these strategies to change and for farmers to choose different 'livelihood pathways' in different seasons and years based on their circumstances. It is also possible for them to pursue different strategies as generations change depending on their asset ownership, income levels, household composition, opportunities available to them, and the vulnerabilities they are exposed to (Scoones, 1998, p. 10). Thus, a historical approach is central to the livelihood analysis (Krantz, 2001). Accordingly, it is recommended that the survey be re-run over time to understand the changes.

The outcome that households surveyed tried to attain was mainly improved food security as they pursued a strategy of farming fish for home consumption and increasing their income along the way. Thus, it seems that the sale of fish was considered only as a secondary or incidental activity for the over 90% respondents who said that their primary strategy was farming fish for home consumption and income generation. This is consistent with small-scale subsistence farming globally (Lynch *et al.*, 2016; Welcomme *et al.*, 2010). The primary outcome for small-scale aquaculture in PNG is increased food security and well-being and reducing vulnerability. Thus, it is important that research for development outcomes also support what households are trying to achieve. As mentioned earlier, it is possible for these strategies to change as farmers may choose different livelihood pathways in different seasons and years. However, this can only be achieved if research for development provides opportunities for farmers to create an asset base that enable them to aspire and pursue other strategies by improving or expanding their farming using the training and information provided by projects such as the ACIAR/NFA-funded project. It is also equally important to note that as households pursue increased food security and household income through fish farming, it is possible for their activities to have detriment impact on the environment or natural resources in the community and increase vulnerability for other households. Thus, the impact of fish farming on the natural environment needs to be assessed to understand the overall impact of the project eg. impact on water access.

7.2.12 Lifestyle choices and outcomes

The aspiration of households surveyed, regardless of the vulnerability situations reported such as resource and ethnic conflict and other natural disasters, was varied. When participants were asked to express their expectations beyond the immediate livelihood strategies, the majority mentioned that they wanted to expand their fish farms so that they can send their children to better schools, build better houses, buy cars and live better lives. These demonstrate that household lifestyle decisions, which are often determined by their dreams and expectations, and their capacity to aspire, are not limited by their immediate livelihood strategies (Appadurai, 2004). Thus, although the immediate objective of research for development might be increasing fish production for home consumption, the dreams and expectations of farmers and their lifestyle choices can be based on their religious and spiritual expectations. Thus, it is necessary to consider religious and traditional values that influence farmers lifestyle choices at the research design stage.

When farmers were asked to state the main religious and traditional driving values in terms of their lifestyle choices, they noted that living a Christian life, respecting and obeying instructions in the community, and contributing to the church were their primary purposes. The Wantok system of reciprocity was also mentioned as one of the factors that influence their lifestyle choices. However, it should also be noted that a few mentioned the Wantok system in a negative sense as a two-edged sword naming that it can be both ‘good and bad’ for household members reasoning that it can encourage nepotism and corruption in society and exclude certain parts of the community. One participant noted that ‘the Wantok system encourages nepotism by local members of parliament to create division in communities; therefore, he argues that basic services are not distributed equitably in PNG.’

7.3 Broodstock management and fingerling production – Objective 3

Two families of GIFT established by FIS/2008/023 were managed under this project and numbers of broodstock increased and distributed by HAQDEC to lead farmers. There was no significant difference in the growth performance of the two families. During Year 1 of the project, the research team reviewed protocols and strategies at HAQDEC for fingerling production, interviewed and surveyed farmers at various skill levels, and also reviewed the findings of the SWOT Analysis, farmer surveys and focus group discussions.

Figure 4 : The HAQDEC-based team with Lara Parata and Jes Sammut. UNSW, NFA and ANSTO formed a strong working partnership with staff at the centre. The HAQDEC team were able to run trials unsupervised during the COVID-19 pandemic. The Australian team conducted formal and informal training activities with the technicians and scientists on the project and mentored them on the ground and remotely. NFA scientists then continued to train and mentor technicians.

As discussed earlier, farmers had poor skills in sexing fish, and even with good skills, GIFT may take weeks to months before they can be sexed. Further to this, our evaluation of farming practices revealed that greater than 83% of farmers were unlikely to invest effort in sexing fish, and many were unwilling to sacrifice female fish or had no additional ponds to farm males and females separately. Farmer interviews also revealed that many farmers could not determine the age of the fish due to stunting and were knowingly or unknowingly selling stunted fish as fingerlings to naïve buyers, who were unaware of what classified a ‘fingerling’. This issue was prevalent across all provinces. It was agreed that moving to monosex fingerling production was an important activity to overcome issues with mixed-sex fish in PNG ponds. Earlier training of staff in broodstock management and hatchery operations, funded by SPC and NFA, had been helpful in improving fingerling production at HAQDEC, but monosex production was not undertaken.

To assist the research under this project, and to introduce monosex fingerling production to HAQDEC and lead farmers, NFA funded training of the team in this technology. Lead farmers and project team members were trained at AIT in Bangkok. On return, the project team conducted a series of trials to produce monosex fish for our experimental work and were able to produce greater than 99% all male fish. Monosex fingerling production was then trialed with lead fish farmers under supervision from Joshua Noiney. Trained lead farmers are now supplying monosex, all male fish to other farmers. Jacob Towa, one of our long term lead farmers, is also supplying prisons in the highlands.   HAQDEC’s capacity to produce monosex fingerlings is now high following further investment in renovating facilities at the centre. During the project, NFA funded the installation of a hatchery modelled in a way that satellite hatcheries could emulate the design – as has now happened. Broodstock management ponds and tanks were also upgraded by NFA and had serviced our trials and assisted in fingerling supply to fish farmers at Yonki and the highlands. Fish farmers from other provinces have also travelled to HAQDEC such that demand was exceeding the capacity to produce fingerlings. NFA has since commenced its program of establishing satellite hatcheries in other provinces which will alleviate the pressure on HAQDEC.

Figure 5: The project team achieved greater than 99% all male, sex reversed fingerlings to support the research. The monosex fingerling production methods were adopted by HAQDEC's fingerling supply program and also taught to lead farmers by Joshua Noiney. The training in sex reversal methods was funded by NFA and conducted at AIT in Thailand. Photo: J.Sammut, UNSW

Joshua Noiney, Billy Kerowa and Micah Aranka have led this NFA contribution. Joshua Noiney has been assisting farmers and provincial officers to establish satellite hatcheries and is training farmers in monosex fingerling production.

Protocols were established for the monosex production method and include human health and environmental risk management given that Methyl Testosterone is the hormone used for sex reversal of females to males. Joshua Noiney will be producing instructional videos with funding from UNSW and the Crawford Fund.

Figure 6. Lara Parata and Joshua Noiney at HAQDEC. UNSW students were able to work alongside the PNG team creating an opportunity for capacity building of students and project staff. Lara's PhD research contributed to the project and was funded by NFA, AINSE and UNSW. Shanice Tong from UNSW was funded by NFA to conduct SLifA surveys in East New Britain. Shanice worked with Provincial Fisheries Officers to build core skills in survey techniques. NFA has been a major supporter of student work and internships under our projects. Joshua Noiney will be studying at UNSW once COVID-19 travel restrictions are lifted, the third team member to study under Jes Sammut. Photo: J.Sammut, UNSW

7.4 Fish feeding trials – Objective 4

This section is based on work also funded by NFA, ANSTO, UNSW and AINSE and is adapted from Lara Parata's PhD contribution to the study and has been prepared as a publication for submission in August 2021: Parata, L., Noiney, J., Majzoub, M.E., Mazumder, D., Egan, S. and Sammut, J. The impacts of farming practice on the productivity and profitability of tilapia farming.

Figure 7: The PNG team was trained in molecular and nuclear laboratory methods, sample preparation for laboratory analysis and sample collection and handling at UNSW and ANSTO laboratories and PNG and Australian field sites. This capacity building was effective with the PNG team completing a series of field experiments during the COVID-19 pandemic. The data quality was high and the findings will be submitted to high impact journals with the project team in PNG as co-authors. Photo: J.Sammut, UNSW.

Figure 8: UNSW provided equipment and on-site training at HAQDEC in fish sample preparation. Training was also conducted with advanced farmers who assisted with sample preparation and data recording. The project team has the capacity to undertake unsupervised work under future research and also contribute to other projects that relate to fish nutrition and food safety. Photo: J.Sammut, UNSW

7.4.1 Isotopic niche space and dietary preferences of GIFT

Analysis of the fish's $\delta^{13}C$ and $\delta^{15}N$ values throughout the experiment revealed that the isotopic signatures and niche size of the GIFT was highly variable. The $\delta^{13}C$ and $\delta^{15}N$ of GIFT at T1 and T2 differed significantly between fish from treatment 1 and treatment 2 (Table 8). At T1 (45 days), there was an increase in the tropic niche space for both treatment 1 (3.80) and treatment 2 (7.68) compared to T0 (stocking) (2.50). However, by T2 (90 days), a decrease in the niche space was observed for both treatments (sweet potato: 3.21; NPK: 3.82), indicating that the fish diet had stabilised (Figure 9). The niche space calculated for fish from treatment 2 (NPK) was larger than that for treatment 1 (sweet potato), suggesting that the addition of NPK (treatment 2) resulted in the fish assimilating $\delta^{13}C$ and $\delta^{15}N$ from a wider range of food items.

Table 8. ANOVA results comparing the $\delta^{13}C$ and $\delta^{15}N$ values of Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from treatment 1 (sweet potato) and treatment 2 (NPK) halfway through the experiment (T1, 45 days) and at the conclusion of the experiment (T2, 90 days).

		Mean (± SE)	Statistics

		Treatment 1	Treatment 2	F Value	P Value
T1					
	$\delta^{13}C$	-24.17 (0.19)	-20.93 (0.32)	67.633	**< 0.001**
	$\delta^{15}N$	9.03 (0.62)	5.11 (0.29)	37.147	**< 0.001**
T2					
	$\delta^{13}C$	-25.15 (0.17)	-20.4 (0.35)	178.7	**< 0.001**
	$\delta^{15}N$	8.45 (0.43)	5.61 (0.16)	30.738	**< 0.001**

The contribution of food sources to the growth of GIFT was calculated at the end of experiment (T2, 90 days). Source mixing calculations to determine assimilation inputs found the contribution of commercial feed pellets and SOM to the growth of GIFT varied significantly between the treatments (Figure 10). In treatment 1, SOM was the dominant food source, accounting for 92.9% of the GIFT diet followed by commercial feed pellets (3.9%), algae (2.8%) and sweet potato (1.1%) (Figure 10). In contrast, in treatment 2 commercial feed pellets contributed the most to the diet of GIFT (53.9%) followed by SOM (34.5%) and algae (11.6%), with NPK excluded from the calculations as it is not directly consumed.

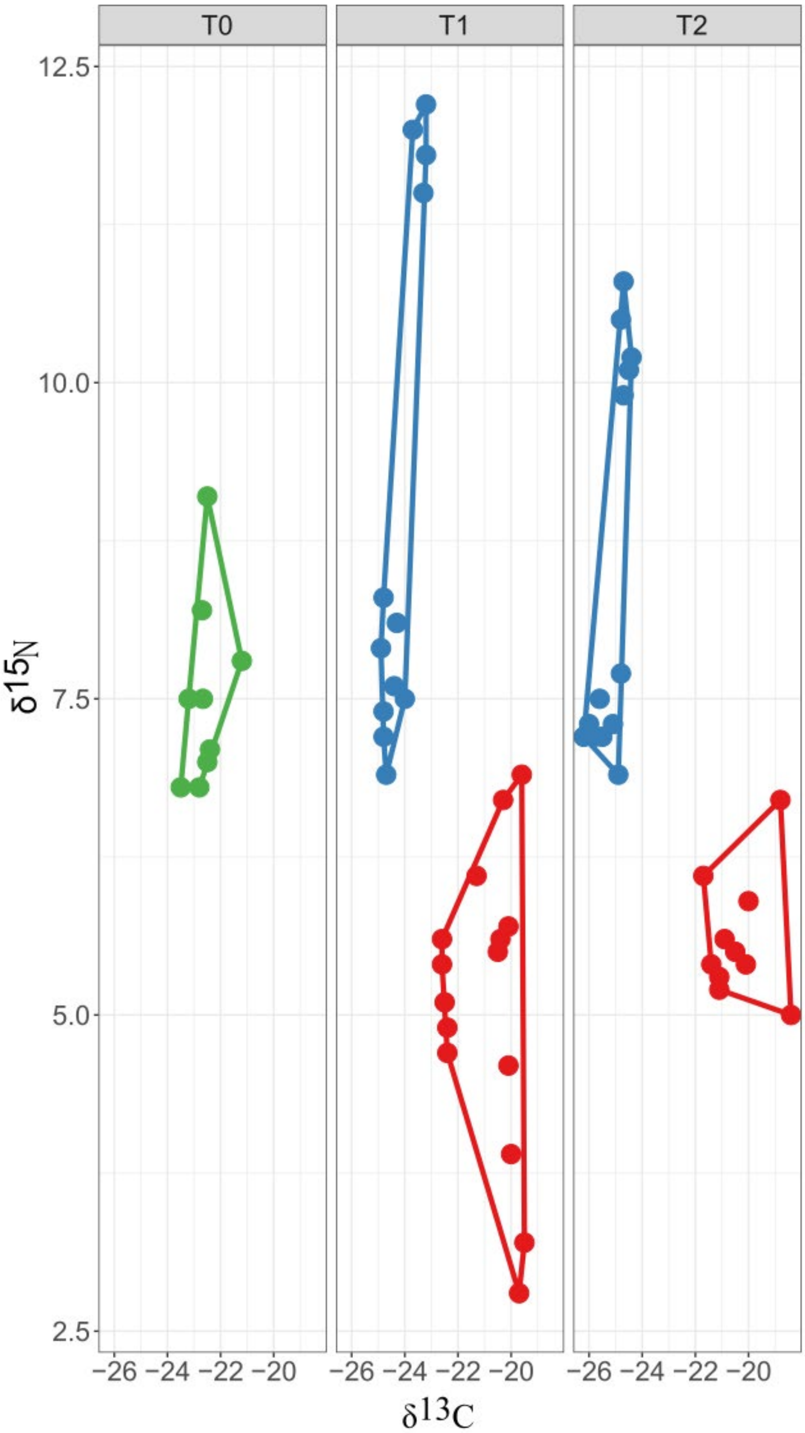

Figure 9. Isotopic niche space using $\delta^{13}C$ and $\delta^{15}N$ of Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from stocking (T0) (green) and treatment 1 (sweet potato) (blue) and treatment 2 (NPK) (red) halfway through the experiment (T1, 45 days) and at the conclusion of the experiment (T2, 90 days). Each point represents and individual fish and lines represent the perimeter of the niche space as calculated by convex hull.

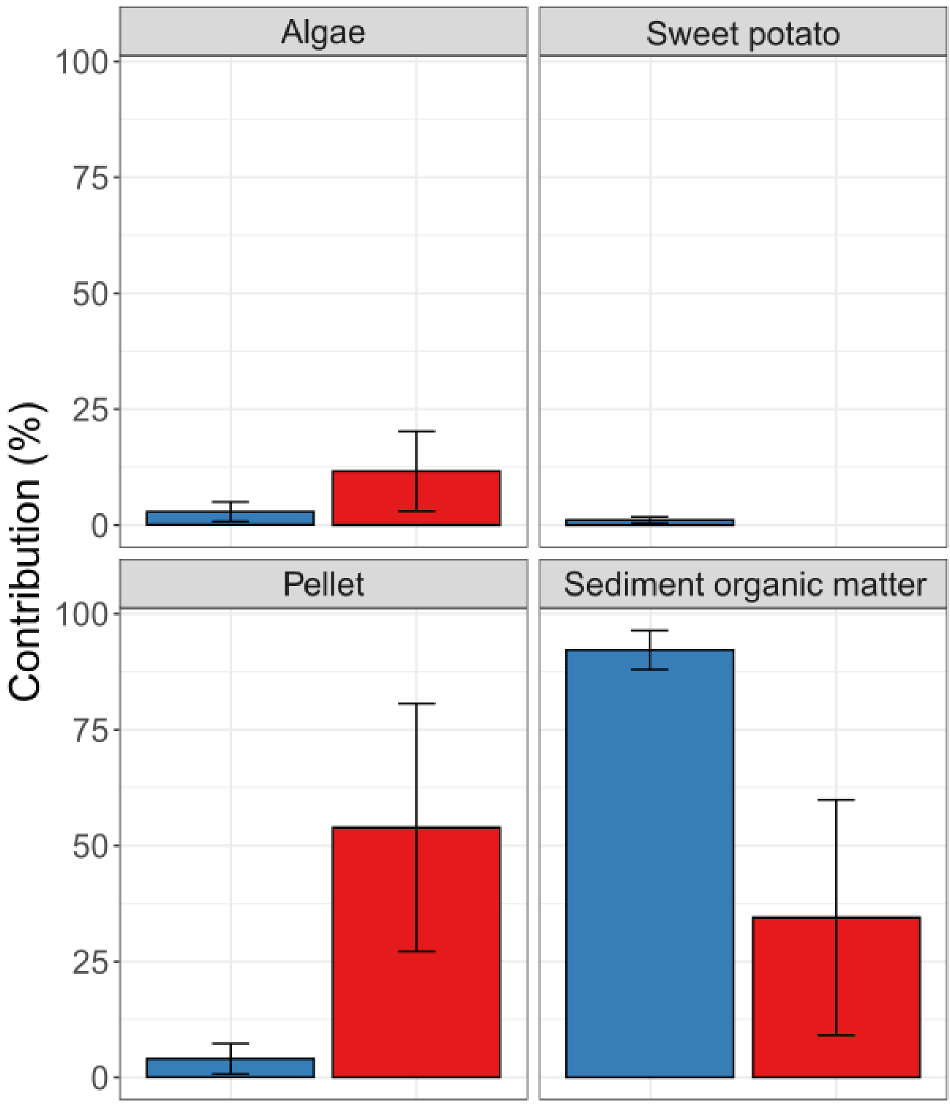

Figure 10. Mean contributions (%) of four potential food sources to Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from treatment 1 (sweet potato) (blue) and treatment 2 (NPK) (red) at the conclusion of the experiment (T2, 90 days). Error bars represent standard deviation. Significant differences in food contributions between treatments were calculated for commercial feed pellets (P = 0.002) and sediment organic matter (P = 0.002) but not algae (P = 0.191).

7.4.2 The gastrointestinal microbiome of GIFT

We used 16S rRNA gene amplicon sequencing to analyse the gut microbiota of GIFT. After quality filtering we identified a total of 5, 318 zOTUs across 70 samples. Rarefaction curves revealed that all samples (post-quality filtering) were sequenced to near saturation (goods coverage > 98%) and hence their bacterial communities were well covered. Alpha diversity as measured by the Shannon-Weaver Index ranged from 0.563 to 5.599. with significant differences identified between the microbial communities sampled from T2 treatment 1 (sweet potato) fish when compared to those from T0 (*P = 0.013*) and T2 treatment 2 (NPK) (*P = 0.034*).

Analysis of the Bray-Curtis dissimilarities revealed a distinct separation of the microbiome of GIFT from stocking, T1 and T2, however, this separation was dependent on treatment (significant time x treatment interaction; *P = 0.001*). At T2, there was significant difference in the microbiota associated with the gastrointestinal tract of GIFT from different treatments (Figure 11 and 12, *P = 0.001*). The relative abundance of 4 bacterial phyla differed significantly between fish reared under treatment 1 and treatment 2. Actinobacteriota and Proteobacteria (*P = 0.005*; *P = 0.009*) were significantly more abundant in fish from treatment 1 (sweet potato), whereas Firmicutes A and Fusobacteria were significantly enriched in fish from treatment 2 (NPK) (*P = 0.007*; *P = 0.038*).

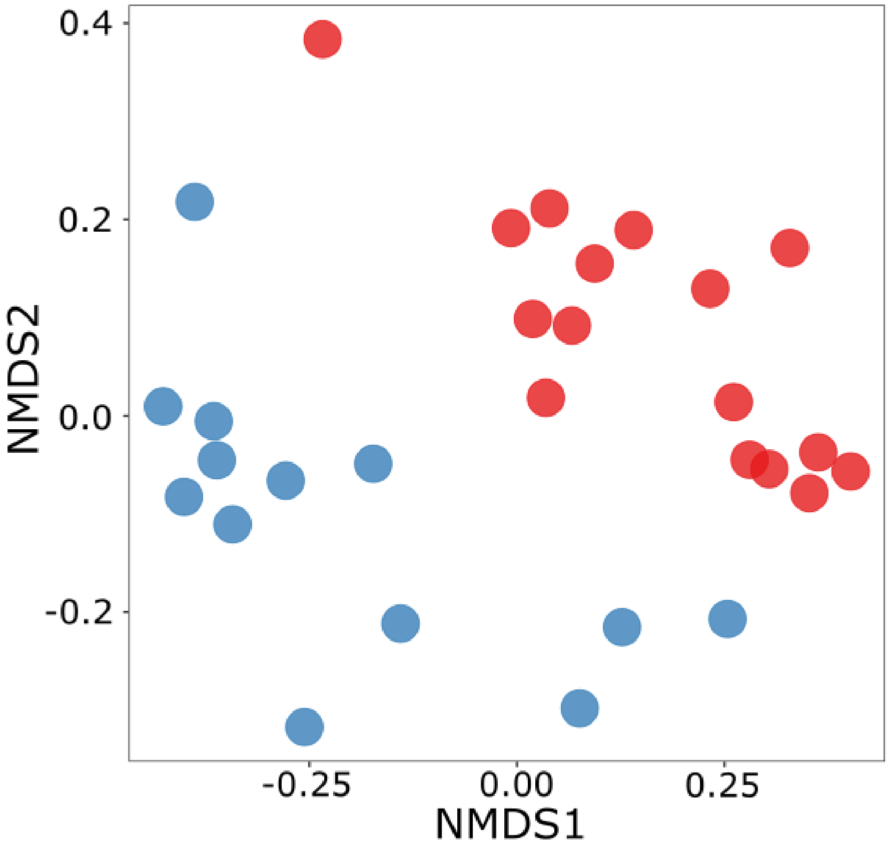

Figure 11. Non-metric multi-dimensional scaling (nMDS) plot based on Bray–Curtis dissimilarity of the bacterial communities associated with of Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from treatment 1 (sweet potato) (blue) and treatment 2 (NPK) (red) at the conclusion of the experiment (T2, 90 days).

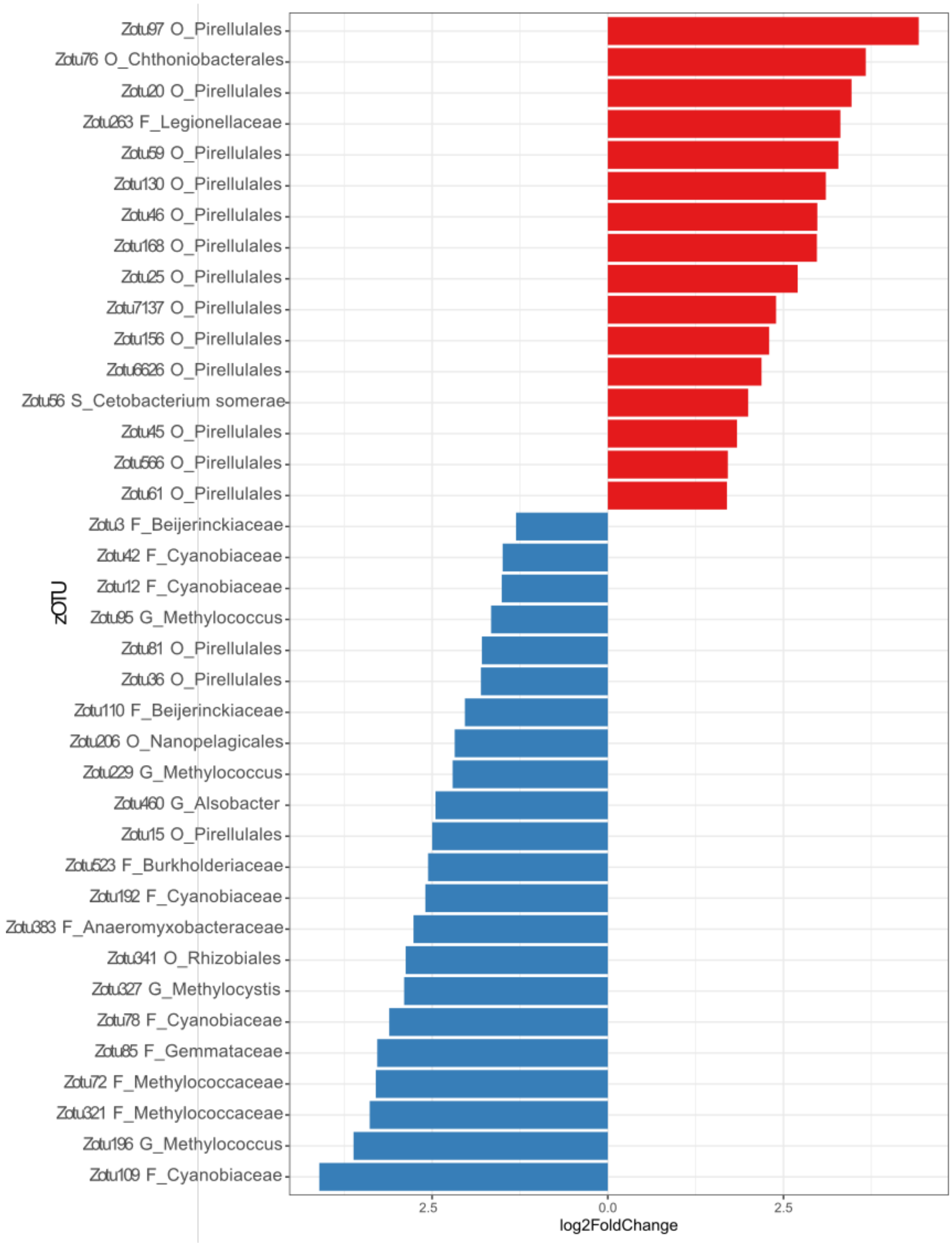

Figure 12. Bacterial zOTUs that were significantly differentially abundant (using Deseq2) in Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from treatment 1 (sweet potato) and treatment 2 (NPK) at the conclusion of the experiment (T2, 90 days). Red columns represent an increase in abundance in GIFT from inorganically fertilised ponds and blue columns represent an increase in abundance in GIFT from the ponds supplemented with sweet potato. Taxonomy annotations reflect the lowest classification using the GTDB database (version 89).

The relative abundance of 38 zOTUs differed significantly between treatments (Figure 11, Appendix B Table B1). Of the 38 zOTUs that were affected by treatment, most were identified taxonomically as Pirellules (45% or 17 out of 38 zOTUs) (Phylum: Planctomycetota), Synechococcales (13%, 5 out of 38 zOTUs) (Phylum: Cyanobacteria), Methylococcales (Phylum: Proteobacteria) (13%, 5 out of 38 zOTUs) and Rhizobiales (Phylum: Proteobacteria) (13%, 5 out of 38 zOTUs) (Figure 12). One bacterial species that differed significantly between treatments was *Cetobacterium somerae*. *C. somerae* accounted for 0.92% of the relative abundance of the bacterial community in fish reared in treatment 1 (sweet potato), and 3.7% within treatment 2 (NPK).

7.4.3 *Growth statistics and water quality parameters*

Throughout this study, no fish mortality occurred. With the exception of fish condition, differences in growth and water quality parameters observed at T1 (45 days) reflected those calculated at T2 (90 days, conclusion of the experiment) (Table 9). At T2, no significant differences were found in water temperature (*P = 0.3*) and pH (*P = 0.822*), however dissolved oxygen (DO) was significantly lower in treatment 1 compared treatment 2 (*P* = *<0.001*) (Table 9). GIFT from treatment 2 were significantly larger (total length *P* = *<0.001* and weight *P* = *<0.001*) than those reared in treatment 1 (Table 9). Furthermore, Fulton's K and profitability were higher and the FCR lower for GIFT in the inorganically fertilised ponds (treatment 2) compared to those produced in treatment 1 (Table 9).

Table 9. ANOVA results showing a comparison of growth statistics, water quality parameters and profitability for Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from treatment 1 (sweet potato) and treatment 2 (NPK) halfway through the experiment (T1, 45 days) and at the conclusion of the experiment (T2, 90 days).

T1	**Treatment 1**	**Treatment 2**	**F**	**P value**
	Average ± SE			
Temperature (℃)	24.11 (0.07)	24.2 (0.06)	1	0.332
pH	7.04 (0.001)	7.03 (0.004)	0.071	0.793
Dissolved Oxygen (DO) (mg/L)	5.67 (0.27)	10.39 (1.29)	12.9	**0.002**
Total Length (cm)	9.02 (0.13)	11.38 (0.19)	106.4	**< 0.001**
Weight (g)	14.18 (0.69)	27.69 (1.61)	59.88	**< 0.001**
Condition (Fulton K)	1.89 (0.02)	1.83 (0.03)	3.266	0.076
T2				
Temperature (℃)	26.34 (0.08)	26.51 (0.14)	1.109	0.3
pH	7.89 (0.06)	7.81 (0.063)	0.051	0.822
Dissolved Oxygen (DO) (mg/L)	6.79 (0.27)	13.73 (0.86)	59.29	**<0.001**
Total Length (cm)	11.1 (0.27)	14.03 (0.14)	99.55	**<0.001**

Weight (g)	24.9 (1.89)	51.64 (1.78)	105.2	**<0.001**
Condition (Fulton K)	1.78 (0.03)	1.86 (0.02)	5.132	**0.0317**
Feed conversion ratio (FCR)	0.59 (0.26)	0.34 (0.05)	1.076	0.309
Profitability ($USD)	15.74 (4.07)	20.91 (3.81)	0.857	0.363

7.4.4 Influence of niche space and host microbiota on farm productivity and profitability

The Mantel test revealed that at the conclusion of the experiment (T2, 90 days) isotopic values, growth statistics, and profitability were significantly correlated with the bacterial communities associated with GIFT (Mantel statistic *r = 0.372, P = 0.0001*). Total length, weight, $\delta^{13}C$ and $\delta^{15}N$ were found to have the strongest correlation with the composition of the GIFT microbiota (Figure 13 Table 10). Total length, $\delta^{13}C$ and weight all correlated significantly with the overall bacterial community composition associated with treatment 2 (NPK); however, $\delta^{15}N$ correlated significantly with the microbiota of the treatment 1 (sweet potato) (Figure 13 Table 10). The relative abundances of 527 zOTUs correlated significantly with at least one growth statistic, with 41 zOTUs correlating with three or more. These 41 zOTUs the majority correlated negatively with total length, weight and $\delta^{13}C$ and were representative of 10 bacterial phyla: Actinobacteriota (3/41), Chloroflexota (1/41), Cyanobacteria (5/41), Firmicutes (2/41), Firmicutes A (1/41), Halobacterota (1/41), Myxococcota (1/41), Planctomycetota (10/41), Proteobacteria (16/41) and Verrucoomicrobiota (1/41). In addition, three zOTUs significantly correlated positively with profitability (Table 4.4).

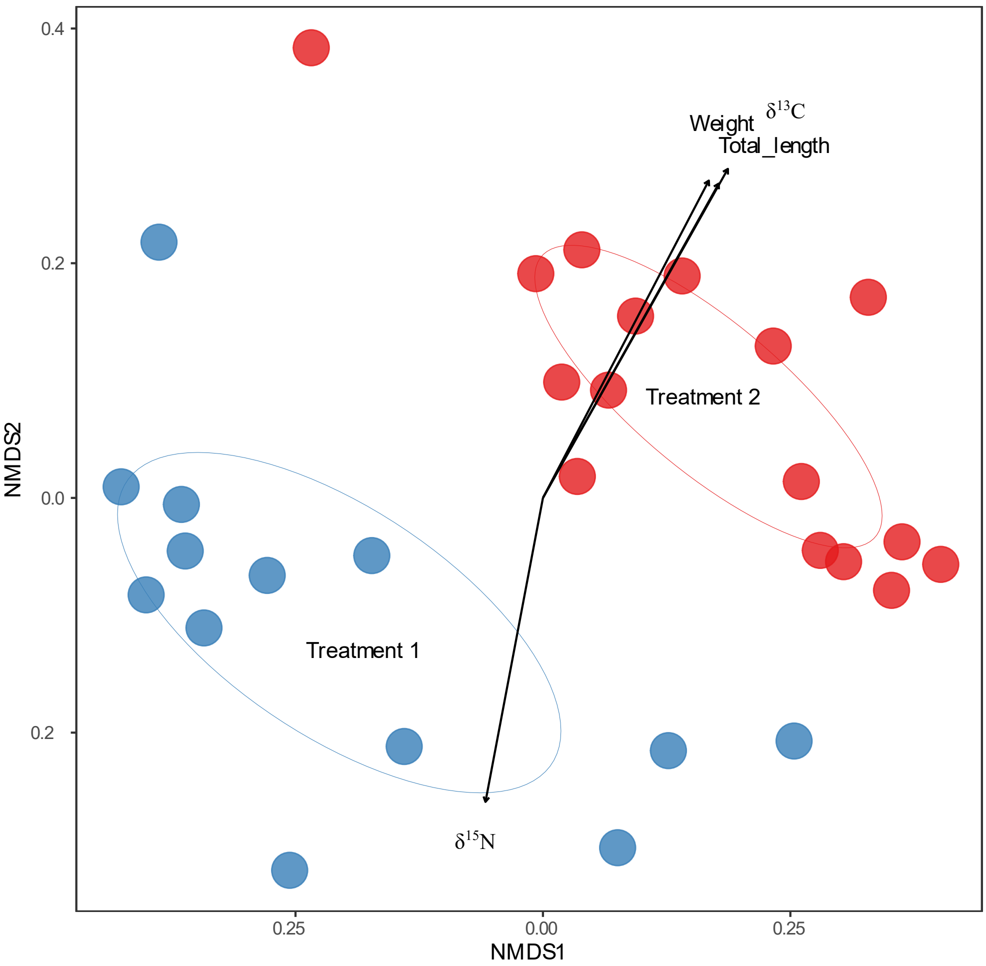

Figure 13. Non-metric multi-dimensional scaling (nMDS) plot based on Bray–Curtis dissimilarity of the bacterial communities from Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*Oreochromis niloticus*) from treatment 1 (sweet potato) (blue) and treatment 2 (NPK) at the conclusion of the experiment (T2, 90 days) with significantly correlated (Pearsons correlation index) growth statistics and isotopic parameters ($P < 0.05$).

Table 10. Correlation statistics showing Pearsons correlation index between bacterial community structure and growth statistics, water quality parameters and profitability at the conclusion of the experiment (T2, 90 days).

	R^2	***P* Value**
$\delta^{13}C$	0.8182	**0.001**
Total length	0.7445	**0.001**
Weight	0.7294	**0.001**
$\delta^{15}N$	0.5077	**0.001**
FultonK	0.1264	0.167
Profit_USD	0.079	0.337
FCR	0.0332	0.69

In this trial we investigated the effects of two farming practices on the success of Genetically Improved Farmed Tilapia (GIFT) strain Nile tilapia (*O. niloticus*) ponds. Through the identification of distinct patterns in nutrient assimilation, diet and microbiome composition, our results show that NPK fertilisation can improve the productivity and profitability of small-scale earthen pond farms. Furthermore, our findings suggest the differences in farm productivity and profitability could be attributed to the microbiota of fish in treatment 2 (NPK) improving their ability to utilise nutrients from commercial feed pellets.

The results of the isotopic analysis conducted in this study suggest that the addition of inorganic fertiliser to earthen ponds triggers a two-staged response in tilapia; an initial diversification of their diet, followed by a shift to a new dietary preference. An initial dietary diversification indicates that adding inorganic fertiliser increases the variety and / or availability of foods, allowing the GIFT to adopt a more generalist foraging strategy. Similar shifts in diet have been previously described by Zhu *et al.* (2020) whereby the addition of fertiliser was found to increase the food available to higher trophic species. It should be noted that while the observed dietary shift between T0 and T1 could be related to ontogeny, the smaller niche space sizes at T2 suggest that is it unlikely that a maturation associated shift occurred and more likely the shift was a response to pond fertilisation.

Additional analyses of the isotopic niche space revealed minimal overlap for $\delta^{13}C$ and $\delta^{15}N$ values throughout the experiment between GIFT from treatment 1 and treatment 2 (Figure 4.1, Table 4.1), further suggesting that the fish were either utilising the available resources differently (Wu *et al.,* 2019) or they were consuming distinct diets (Kadye and Booth, 2012). The $\delta^{15}N$ values revealed that fish from treatment 1 were significantly enriched in nitrogen compared to those in treatment 2 (Figure 4.1, Table 4.1). An enrichment in nitrogen would generally suggest the fish consumed a more protein rich diet (Beltrán *et al.,* 2009); however, fish from treatment 1 assimilated most of their nutrients from the SOM, which is considered to be low in protein (in our study SOM protein = ~1.25%, C:N ratio 10.91). This enrichment in nitrogen amongst fish from treatment 1 was unexpected because fish within treatment 2 assimilated more than ten times as many nutrients from commercial feed pellets (Figure 4.2), a food generally considered to be protein rich (Craig and Helfrich, 2017) (in our study pellet protein = ~30%). Given the disparity in protein levels between SOM and commercial feed pellets, it is unlikely that fish from treatment 1 were consuming a more protein rich diet. Rather, it is possible that the enriched nitrogen observed in our study is a sign of malnutrition (McCue and Pollock, 2008), a hypothesis further supported by the high C:N ratio of their main food sources (SOM C:N = 10.91; algae C:N = 15.31, sweet potato C:N = 77.97) (Yokoyama *et al.,* 2005) and the relatively poor condition of fish reared in treatment 1 (sweet potato) (Table 4.2). Together, these results suggest that the addition of inorganic fertiliser significantly improves the GIFTs ability to utilise the pellet component of their diet, resulting in increased farm productivity. This finding is important because farming fish in conditions wherein they cannot utilise available nutrients can limit farm productivity, thus deterring communities from engaging in farming activities.

The gastrointestinal microbiota of fish plays a significant role in facilitating nutrient assimilation and digestion (Nayak, 2010; Ray *et al.,* 2012; Romero *et al.,* 2014); therefore, we can expect changes in dietary preference and niche space to be reflected in the structure of these communities. We found that the application of inorganic fertiliser significantly altered the composition of the GIFT microbiota (Figure 4.3 and 4), potentially enhancing their ability to assimilate available nutrients (Figure 4.2). One bacterial species that was differentially abundant in GIFT based on pond treatment was *Cetobacterium somerae*. *C. somerae* has been identified as a common constituent of the microbiome of freshwater fishes (Tsuchiya *et al.,* 2008) including goldfish (*Carassius auratus*) (Sugita *et al.,* 2017a), carp (multiple species) (Eichmiller *et al,.* 2016) and tilapia (Sugita *et al.,* 2017b), and is thought to be associated with the production of vitamin B12 (Sugita *et al.,* 1991; Tsuchiya *et al.,* 2008). The role of vitamin B12 in fish is not yet fully understood; however, in other animals, it plays an important role in producing red blood cells and maintaining the health of the nervous system (Oh and Brown, 2003; Reynolds, 2006; Stabler, 2013). A deficiency in B12 can be caused by a low protein diet and can result in malabsorption of food material (Reynolds, 2006; Stabler, 2013). In our study, the relative abundance of *C. somerae* was four times higher in the microbiome of GIFT farmed in treatment 2 (NPK) than those from treatment 1 (sweet potato). These results suggest that a lack of dietary protein and low abundances of *C. somerae* in GIFT from treatment 1 could be limiting their B12 intake, resulting in widespread malabsorption of available nutrients. This finding could provide an explanation for the lack of nutrients assimilated from commercial feed pellets by GIFT within treatment 1 and subsequently their nitrogen enrichment, and poor condition.

Similar to *C. somerae*, the relative abundance of zOTUs belonging to Pirellulales correlated positively with growth parameters (i.e., associated with good growth) (Figure 4.4 and 4.5, Appendix B Table B2). Pirellulales are not commonly described as constituents of fish microbiotas; however, they have been associated with freshwater lakes (Schlesner, 1994; Dedysh *et al.,* 2020) and seagrass meadows (Jiang *et al.,* 2015) where they are thought to play a role in nitrogen fixation. The involvement of Pirellulales in nitrogen cycling may explain its presence in freshwater GIFT, particularly in the inorganically fertilised ponds. Under these conditions, the fish were deficient in dietary nitrogen and may have been trying to compensate for this by harbouring nitrogen fixing bacteria. Comparable results have been reported previously by McDonald *et al.,* (2015) who suggested that under nitrogen limiting conditions the gut of catfish (*Panaque nigrolineatus*) harbours nitrogen fixing bacteria. Similarly, it has been reported that arthropods that are deficient in dietary nitrogen harbour nitrogen fixing bacteria to supplement their poor diet, with this symbiotic relationship thought to improve their nutrition (Nardi *et al.* 2002). Together these studies suggest that Pirellulales could be helping the GIFT sampled from treatment 2 nutritionally compensate for their nitrogen deficient diet.

Whilst an increase in the relative abundance of bacteria such as *C. somerae* and Pirellulales may benefit GIFT, we found multiple zOTUs belonging to Rhizobiales (Phylum: Proteobacteria) whose relative abundance correlated negatively with growth parameters (i.e., associated with poor growth) (Figure 4.4 and 4.5, Appendix B Table B2). Rhizobiales were more abundant in fish sampled from treatment 1 (sweet potato) (Figure 4.4, Appendix B Table B1). In plants and lichens, Rhizobiales have a symbiotic role and are thought to play a part in the regulation of cell growth hormones and vitamin production (Erlacher *et al.,* 2015; Garrido-Oter *et al.,* 2018). In fish, McCauley *et al,.* (2020) speculated that Rhizobiales could play a role in nitrogen fixation, however, they did note that it is not known whether this is important from a biological standpoint. These findings indicate that Rhizobiales could have a beneficial role in GIFT, therefore, their association with poor growth warrants further research. This further research should aim to characterise the functional roles of Rhizobiales and other growth associated taxa such as *C. somerae* and Pirellulales within the gastrointestinal tract of tilapia and elucidate how their relative abundance can be modified using different nutrient inputs and / or farming practices to further improve farm productivity.

Our study showed that farm profitability was positively correlated with three zOTUs: *Bacillus* (Phylum: Firmicutes), *Romboutsia* (Phylum: Firmicutes A) and Patescibacteria (an unculturable bacteria) (Table 4.4). Previous studies have reported that *Bacillus* can have probiotic functions in aquatic species such as freshwater prawns (*Macrobrachium rosenbergii*) (Deeseenthum *et al.* 2007), red sea bream (*Pagrus major*) (Zaineldin *et al.,* 2018) and Nile tilapia (*Oreochromis niloticus*) (Elsabagh *et al.,* 2018). For example, Zaineldin *et al.* (2018) demonstrated that after 60 days *Bacillus subtilis* improves the growth and feed conversion efficiency of red sea bream. Similarly, Elsabagh *et al.* (2018) found that the addition of *Bacillus* based supplements improves the weight and FCR of tilapia in earthen ponds. Unlike *Bacillus, Romboutsia* are commonly isolated from soils (Wang *et al.,* 2015) and the gastrointestinal tract of mammals (Gerritsen *et al.,* 2014; Maki *et al.,* 2020). Within the gastrointestinal tract of healthy humans, *Romboutsia* are known to ferment carbohydrates and numerous amino acids (Gerritsen *et al.,* 2019), possibly explaining their presence in GIFT. In terms of fish farming, carbohydrates are typically found in high proportions in commercial fish feeds due to their binding properties and relatively low cost (Kamalam *et al.,* 2017). Here we show that fish in treatment 2 (NPK) were significantly enriched in $\delta^{13}C$ (Figure 4.1, Table 4.1) and relied heavily on commercial feed pellets for nutrients (Figure 4.2). Under these conditions *Romboutsia spp.* could be facilitating the digestion and assimilation of this food source. This finding is significant because despite commercial feed pellets being the largest expenses outlaid by farmers, they are an essential part of aquaculture, that promote and enhance the growth of farmed GIFT (Parata *et al.* 2020). From an economic standpoint, an improved assimilation efficiency from the commercial feed pellets allows farmers to justify purchasing expensive feeds. The potential for *Bacillus* and *Romboutsia* to have positive effects on the profitability of farming GIFT suggests that future work should look to determine the exact function of these bacteria in the tilapia gut and the role they play in increasing farm profitability before beginning to develop methods for increasing their relative abundance.

7.4.5 Scientific and management relevance

The results of this study contribute to a growing body of work aiming to improve the food and income security of communities in developing nations through subsistence fish farming. We found that NPK fertilisation can improve not only the productivity but also the profitability of small-scale tilapia farming. These findings are significant not only for the health and financial status of farmers, but also the surrounding populations. Our results demonstrate the extent to which nutrient inputs are associated with growth and the gastrointestinal microbiota composition of GIFT. Therefore, the outcomes of this work provide an important reference to develop new aquaculture management programs in developing countries whereby farmers can be informed about the costs and effectiveness of alternative feeding practices for low intensity fish farming. Since conducting this research, other studies have also alluded to the importance of understanding the role of gut microbes in nutrient assimilation as means of developing better feed formulations and manipulating pond conditions to benefit fish. Future research should evaluate the effect of NPK on fish quality from a human nutrition perspective and determine whether similar farming practices would improve the production of other commonly farmed freshwater fish species. Furthermore, studies should look to assess the applicability in other developing nations where populations have low income and face difficulties in accessing dependable sources of protein. The work also shows that inorganic fertiliser is more effective than organic fertiliser or using sweet potato as a source of nutrients, and supports the findings of Narimbi et al (2018). The results from this objective will also underpin future trials on fish formulations for cage-based farming and pond-based farming. Linked work by Parata (UNSW) will contribute to the design of trials on higher intensity systems.

Figure 14: Cage-based farming is the most likely pathway to higher intensity farming for income generation. This farm is located in Yonki Reservoir where the team collected fish samples to compare gut microbiomes of cage fish with wild and pond-reared fish. Photo: J.Sammut, UNSW.

7.5 Key achievements resulting from the research and associated dissemination activities

The projects main achievements include:

- Improved feeding strategies to minimise production costs and optimise the growth of farmed fish
- Expansion of a lead farmer network across eight provinces
- Increase in quality fingerling supply from HAQDEC and satellite hatcheries funded by NFA using technologies from the collaborative project and NFA-funded training of staff
- Successful trials on monosex fingerling production have enabled HAQDEC and satellite hatcheries to clear production bottlenecks that were associated with reproduction of fish in ponds – this usually resulted in stunted fish and wastage of feed
- The project has provided technical support to the NFA Fish for Prisons and Fish for Schools programs, and contributes to the Maria Kwin Training Centre's accredited certificate level aquaculture course

- New knowledge on factors that aid nutrient assimilation from different food sources were incorporated into feeding strategies and have created a scientific baseline for future research on the nutritional requirements of fish in higher intensity pond and cage-based farming systems
- Social and economic benefits from the project include reduced crime and tribal fighting, increased access to protein, lower production costs, improved pond yields, improved lifestyle, reduction in violence against women and children, and improved human health
- A Sustainable Livelihoods and Lifestyle Survey and associated SWOT Analysis for eight provinces in PNG generated knowledge used by NFA to develop a roadmap for aquaculture development in PNG.
- The project team's research capacity has increased significantly demonstrated by a series of successful field trials using nuclear, nutrition and microbiological research methods taught at UNSW and ANSTO and onsite.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Stable Isotope Analysis as a tool in fish nutrition research

The project applied nuclear approaches to understand nutrient assimilation that ANSTO and UNSW had commenced developing under FIS/2008/023 (Narimbi *et al.,* 2018) and their other aquaculture and seafood provenance collaborative projects (Gopi *et al.*, 2018; 2019a; 2019b; Sammut et al, 2021a). Stable isotope analysis, Stable Isotope Mixing Models (SIMM), and novel tissue sample preparation methods developed by the ANSTO-UNSW team in Australia were successfully used to accurately identify the source of assimilated nutrients that contribute to tilapia growth. Traditional methods of understanding how nutrients from a variety of sources contribute to fish tissue growth are usually cumbersome, require multiple treatments, or difficult to apply in pond-based studies. They are also often based on a false assumption that digestibility is equivalent to assimilation; this is not the case, and the approach used by the project has already dispelled some misconceptions regarding the value of organic fertiliser (Narimbi *et al.,* 2018).

As a result of our work and that from our previous study (FIS/2008/023), and findings from our linked projects in Australia, we have demonstrated that stable isotope analysis is an appropriate method not only for improving fish nutrition research, but also for trophic positioning studies, determining or predicting the impacts of cage-based aquaculture in lake systems, developing carrying capacity models, and selecting ingredients for new fish feed formulations. A testament to this is our related work in high impact journals being cited regularly, and the methods we employed being adopted by other studies. As we progress with more publications from this project, we expect further uptake of the methods in fish nutrition research. These methods are important for developing sustainable and low impact higher intensity farming systems eg cage-based farming and semi-intensive farming systems in PNG. This knowledge underpins some of the methods that are incorporated into a new proposal for inland aquaculture in PNG. We note that the PNG-based team was trained in this methodology at UNSW and ANSTO, as well as the HAQDEC laboratory. A high level of competence was achieved as demonstrated by the PNG-based team completing 1.5 years of trials without supervision – quality data were generated and the findings have been written up and will be submitted to high impact journals. We also note that NFA has funded similar equipment for PNG to support future research on feeds. However, to maximise the benefits, further training and capability development is needed, and this is addressed under two pipeline projects. UNSW and ANSTO staff have committed to provide longer-term skill building in this methodology, which also has the potential to be applied to PNG's efforts to meet seafood quality certification for exports. This component of the study demonstrated the importance of building scientific skills in PNG staff, which is consistent with NFA's push for increasing scientific capacity through research-based, work-integrated learning.

Molecular methods in fish nutrition research

The project, through its links to Lara Parata's PhD research and an AINSE-funded scholarship, was able to conduct research on the gut microbiome of caged, wild and pond-farmed tilapia. Such work has not been previously attempted. The PNG team was trained in molecular techniques at UNSW and at HAQDEC by the UNSW team. The findings of this study creates a basis for future work on tilapia and other species, specifically to investigate if modified gut microbiomes can enhance assimilation of nutrients from feed ingredient replacements. Accordingly, the scientific knowledge can be used in pre and probiotic research on fish feeds and how feeding practices, farming conditions and feed sources can influence fish growth via microbiomes. We have published one paper (Parata *et al.*, 2020) and have several others that are being submitted in August 2021, which include the HAQDEC and Goroka team members as authors. As for other capacity building, the PNG team acquired essential skills that enabled them to undertake unsupervised research that generated quality data.

Fertiliser/Feed trials

The feed and fertiliser trials built on the FIS/2008/023 findings. We have shown that for small-scale, low intensity farming, wasteful practices that lead to large Feed Conversion Ratios, can be abandoned in favour of lower frequency supplementary feeding and application of inorganic fertiliser. The study also used the above mentioned methods to demonstrate how inorganic over organic fertiliser can produce better growth in low intensity fish farming. In terms of scientific impact, the project showed the value of combined nuclear and molecular techniques to address research questions more efficiently. As stated earlier, NFA team members capably conducted this research as a result of capacity building under the project, delivered by UNSW and ANSTO, with additional funding support from NFA.

8.2 Capacity impacts – now and in 5 years

The NFA team members at HAQDEC have successfully conducted field trials with minimal supervision. We are confident that they now have sufficient field and laboratory skills to conduct other trials beyond the life of this project and contribute to any future ACIAR-funded project involving aquaculture research. An outcome of the capacity building, by the NFA funded contributions and related project training, has been an increase in fingerling production at HAQDEC. NFA's satellite hatchery program has helped to ease the escalating demand for fingerlings due to the rapid growth of cage-based farming. The technical capacity of Provincial Fisheries Officers has also increased. With support from NFA, Provincial Fisheries Officers have taken the lead with training farmers and have lessened the workload for the project team and other NFA officers. Farmer capacity has increased; trained farmers are now regularly producing table size fish. The lead farmer network has also expanded under the project, and NFA has employed some lead farmers to assist with extension work.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The main economic impacts of the project include:

1) Reduced need for commercial feeds for small-scale farming which equates to approximately an 80% reduction in cost of commercial feed. However, the cost of inorganic fertiliser, which varies across the country, needs to be considered.
2) Reduced labour costs for farms that stock monosex fingerlings
3) Fingerling production as a second source of income is an option for advanced farmers, but also increasingly evident in less advanced farmers who are now using monosex fingerlings.
4) Increased fingerling supply and support from SPC and NFA has enabled cage-based farming to grow, although feed supply issues are currently being addressed by NFA's subsidised feed program.
5) Successful farming has enabled farmers to sell fish whilst still meeting household protein requirements

8.3.2 Social impacts

The data from the Sustainable Livelihoods and Lifestyle Surveys, focus group meetings and farmer interviews showed that farmers involved in fish farming training were able to increase yields and income, as well as improve access to protein by adopting practices developed by the project. The reported benefits from fish farming included increased access to better education for children and women, increased purchasing power for household items, reduced crime and tribal fighting, better health, and a reduction in malnutrition (Sammut *et al.*, 2021a). As was postulated at the start of the project, based on the project team's experiences on FIS/2008/023 and NFA projects, fish farming was found to reduce idleness, raise self-esteem, and foster collaboration between farmers and communities. These impacts were well reported by farmers and considered factors in driving down crime and reducing tribal conflicts. The Sisters of Notre Dame, at the Maria Kwin Centre, have used fish farming in their Personal Viability training, and to help former Raskol gang members to build self-esteem.

Jacob Wani's team manages the Fish for Schools and Fish for Prisons program, which this project linked to; these are also examples of how fish farming can be life changing. The Fish For Schools program, which utilises knowledge of fish farming as the basis of teaching a variety of topics, also raises confidence in children and young adults, and instils a sense of hope for the future. Gideon Pama (Freshwater Aquaculture Manager), who coordinates the high school level program for NFA, reported that students encourage their families and communities to adopt fish farming as a means of increasing access to protein or a primary or secondary livelihood. The students train their families and communities to farm fish, creating another knowledge pathway in the community. Fish farming is also adopted as a livelihood by many students who graduate from school and don't have qualifications for tertiary level training or unable to pursue other career paths.

The Maria Kwin Centre has continued to provide fish farming training to women ostracised from the community due to sorcery accusations, or have left their household due to domestic violence. Sister Pauline Kagl has also reported a decrease in domestic violence due to better livelihood outcomes and increased self-esteem of men involved in fish farming.

NFA has had success with various social interventions utilising the expertise of the NFA staff on the ACIAR project team. A recent example is the project team's role in helping people with drug addiction to build their self-worth. NFA has been working closely with a non-government organisation, the Drug Abstinence Rehabilitation Centre (DARC), utilising fish farming to drive change in the lives of people who have become outcasts due to drug abuse. The members of DARC were once heavily involved in consuming illicit drugs, were warlords or raskol gang members, and illegal miners at Pogera mine. NFA continues to provide technical advice and hands-on practical lessons on pond construction and fish husbandry. The involvement of the NFA team has helped to grow the membership (now at 232 members). The ponds constructed by the members will be stocked with all male fingerlings sourced from a privately-run hatchery operated by Mr Jacob Towa, in Mt Hagen. Jacob Toa is one of the project's lead farmers and will help mentor participants in the DARC program.

8.3.3 Environmental impacts

The improved feeding strategies reduce waste and reliance on fishmeal-based diets which are universally considered as unsustainable due to the pressure on wild fish stocks, which include species that are important for the food web. The pond-based farming methods, tested and promoted by the project, do not contribute nutrient loads in nearby rivers; rather, any effluent is utilised in vegetable gardens. Monosex tilapia also minimise but not eliminate the potential for escaped fish to establish wild populations; we note that tilapia were introduced decades ago and are already present in most river systems.

Nevertheless, monosex fingerlings reduce the risk of introducing new strains that might have a competitive advantage over endemic species of fish.

8.4 Communication and dissemination activities

Stakeholder engagement

The project team engaged with farmers on a regular basis. The main formal mode of stakeholder engagement included:

1) Farmer training workshops and information sessions on project breakthroughs; topics included broodstock management, fingerling production, business management, feed production, feed strategies, pond design and construction, pond water quality management and general fish husbandry.
2) Lead farmer training and mentoring – during this project, the number of lead farmers increased to more than 30 farmers. NFA was very supportive in developing the capabilities of lead farmers and also by providing financial support to establish services at strategically located farms. Lead farmers were selected on the basis of their baseline capacity, role in the community, location of farm, and their ability to train and influence others. Each lead farmer was a node in a network of wantoks; this facilitated broader transfer of knowledge and also provided a pathway for feedback from farmers to the project team.
3) Focus group meetings and interviews with farmers to assess the evolving needs of the industry – these were held during the SLifA surveys and when the project needed to realign activities. Focus group meetings and interviews were conducted in 8 Provinces and some island communities.
4) Regular meetings with NGO programs to disseminate knowledge relevant to their interventions
5) Training of Provincial Fisheries Officers and also work-integrated learning activities in 8 provinces (skill building in conducting surveys)
1) Maria Kwin Centre Certificate in Aquaculture (TVET level course); The project team has continued to support the Maria Kwin Centre to deliver certificate level training. This is made possible by NFA's financial support of the centre and allocation of staff time to assisting the program. NFA has also established a hatchery at the centre and the project team has trained teachers and farmers at the facility.
6) Community training by Sisters of Notre Dame
7) Training of prisoners was undertaken at Bihute and Bundara Prisons by the team, and at other prisons by lead farmers. This involved the transfer of knowledge from the current and past ACIAR and NFA projects and was funded and coordinated by NFA. This should be made clear in any ACIAR media stories to ensure proper credit to NFA.
8) Training of a women's group was undertaken in Enga Province. The participants were trained in fingerling production, fish feeding strategies and feed production, fish husbandry, and running a farm as a business.
9) Provincial level training also involved Provincial Fisheries Officers across the country. A good example of this is the work undertaken by Esther Karahure, and Morobe Provincial Fisheries Staff, trained by the project and by NFA. The staff conducted training in hatchery methods, feed production and fish husbandry to small and large groups of farmers throughout the province. Esther is also running training at Potsie Village, close to Lae, where NFA has supported the establishment of a satellite hatchery. The location was also previously used by the project to train retiring PNG military staff and new farmers.

Figure 15: Francis Gako from our project team training women from the Maria Kwin Training Centre's Graduate Certificate in Aquaculture. The project team contributes to training at the centre to ensure current technologies are available to the students. Photo: J.Sammut, UNSW

Informal training of farmers included:

2) Information sharing via the project office and feed mill at Goroka where the core field-based team operated
3) Information sharing at the HAQDEC hatchery when farmers collected fingerlings
4) Site inspections at Yonki Reservoir
5) Informal training following fieldwork and surveys (8 Provinces)
6) Information sharing via farmer participation in field trials in Eastern Highlands Province and Yonki Reservoir
7) Information stalls at the Goroka Show and Nari Agricultural Show

Due to the COVID-19 situation, extension work by the project team in PNG was reduced in 2020 and 2021. Farmer workshops could not be conducted from February to June 2020 due to bans on gatherings, travel restriction, and occasional local lockdowns in various provinces. Nevertheless, the team provided technical support to lead farmers and satellite hatcheries under NFA's program. Prior to the restrictions, the project team regularly conducted feedback sessions with farmers in eight provinces and continued to work with lead farmers to promulgate findings in the fish farming communities. The Crawford Fund has awarded UNSW and NFA a grant to produce instructional videos for farmers (to be used on Android phones) so the team can disseminate technical information safely during COVID-19. UNSW is also contributing $50,000 in cash that was provided by a philanthropist impressed by the work undertaken in PNG. The UNSW funds will contribute to pilot trials of PhotoVoice, production of additional extension videos and scoping of phone-based applications to capture farming data and assess impacts of farming technologies. There is potential for further funding from the anonymous donor.

Extension work at the prisons was restricted from April 2020 to the end of the project to minimise risks to prisoners. However, training was regularly undertaken before restrictions were in place. Prisons in other provinces were visited by the Port Moresby-based NFA staff. Similarly, there was less activity on the Fish for Schools program to minimise risks, and also because of temporary closures of schools.

We note that NFA has made a sustained effort to disseminate fish farming knowledge and will continue this effort beyond the project. The Aquaculture and Inland Fisheries Unit has also developed strategies based on the aquaculture related Corporate Planning goals for NFA.

Figure 16: The project team, through NFA funding, established a new hatchery at HAQDEC and embarked on all-male, sex-reversed fingerling production. The methods and simple infrastructure needed to produce the fingerlings were the basis of NFA's satellite hatchery program in the provinces.

Figure 17: NFA's contribution to the project has enabled the team to promulgate technologies into the provinces thereby increasing uptake of knowledge and technologies. The Aquaculture and Inland Fisheries Unit also facilitate partnerships with NGOs and farming cooperatives.

Presentations and Seminars

- Lara Parata gave a presentation on the feed trials at Aquaculture America in Hawaii in February 2020. Her attendance was funded by her AINSE Residential Scholarship.
- Debashish Mazumder and Jes Sammut presented the research during a Webinar organised by the Indonesian Ministry of Marine Affairs and Fisheries in June 2020.
- Jes Sammut presented the project findings to a webinar on maximising development impact from research. The webinar was run by the UNSW Institute for Global Development in April 2020.
- Jes Sammut presented project findings to ANSTO in 2018 for the institutes research seminar series.
- Jes Sammut presented project findings to the Centre for Marine Science and Innovation, UNSW in 2019.
- Research methods and case studies from the project were included in course materials (lectures and tutorials) for 3 undergraduate and 2 postgraduate courses at UNSW.

Media

- Jes Sammut was interviewed by the ABC on its Pacific Beat radio show in 2019.

- Havini Vira, Lina Pandihau and Jes Sammut were interviewed on fish farming on Radio Manus local radio. Arranged by the Australian High Commission's Public Diplomacy section.
- Jes Sammut was interviewed by NBC Radio in 2016 on the broader fisheries program in PNG. Arranged by the Australian High Commission's Public Diplomacy section.
- The Farming Fish for Change video was aired on prime time and for a repeat slot on EM TV in 2019. It was also posted on YouTube.

Social media:

- https://www.facebook.com/UNSWaquaculture/
- https://www.facebook.com/inlandaqua2014/
- https://twitter.com/AquacultureUNSW
- https://twitter.com/JesSammut

Websites:

- UNSW Centre for Marine Science and Innovation Facebook Page: https://www.facebook.com/unswcmsi/
- UNSW School of Biological Sciences Facebook Page: https://www.facebook.com/unswbees
- UNSW Science Facebook Page: https://www.facebook.com/UNSWScience/
- UNSW Global Water Institute: http://www.globalwaterinstitute.unsw.edu.au

9 Conclusions and recommendations

9.1 Conclusions

Small-scale farming of GIFT in earthen ponds will likely remain the primary mode of tilapia production in rural PNG due to the remoteness of many farm locations, and a lack of financial and physical capital to enable scaling up of production. This was evident in the interviews, focus group discussion and SLifA survey results; small scale farmers prioritised tilapia production for protein and considered income as a secondary opportunity. Other impediments to scaling up is the lack of access to commercial feed, and lack of financial assets. Although our research demonstrated that small-scale farming goals could be achieved ie to meet household and nutritional needs, we also identified access and cost of feed for commercial scale production a barrier to many farmers. Nevertheless, opportunities for scaling up production for income security existed for advanced pond-based farmers, particularly those close to urban areas, infrastructure and a retail market, and cage-based farmers who entered fish farming with a higher financial base from other ventures. Cage-based farmers were also usually better skilled in business development and were entrepreneurial. The NFA Aquaculture and Inland Fisheries Unit, the main partner on this project, has indicated support for research on cage-based culture, outlined in Section 9.2, continued support for small-scale farming in other provinces, particularly in lowland areas where environmental conditions are markedly different to the highlands, and capacity building which has been transformative, to date, for the Unit.

The SWOT Analysis and SLifA findings suggest that the social capital of rural fish farmers is high and a driver for people to consider fish farming as livelihood. The high level of social capital offsets low financial capital in that farmers can utilise community members as a source of labour, resources can be shared to establish and operate farms, and fish can be exchanged for other services. The associated interviews also captured a consistent narrative around the social benefits of fish farming. As was found for FIS/2008/023, fish farming enhanced lifestyles, reduced crime and tribal fighting, and built strong community ties. Farmed fish consumption was also associated with improved health and a reduction in undernutrition in the community, particularly for children (Sammut *et al.*, 2021a; Hiruy *et al.*, 2021).

The project demonstrated that for small-scale, pond-based fishing farming in PNG, weekly fish feeding is more profitable and sustainable for the level of farming intensity. Inorganic fertiliser was found to be more suitable to stimulate natural food production than organic fertilisers. The research also demonstrated that vegetable waste as an alternative feed is not directly contributing to growth of fish. Nevertheless, addition of vegetable waste is still encouraged as it can play a role in stimulating natural food production.

The project was part of a series of projects involving a core team of NFA researchers, technicians and managers. During this program of research, the capabilities of the PNG team significantly improved such that quality data were generated from field trials conducted by the team during the COVID-19 pandemic. Some of the results are already published and manuscripts are being prepared. This is a significant outcome for the PNG-based project team in that it has demonstrated that capabilities have increased as a result of training, mentoring and work-integrated learning – and this is particularly important for the team based in rural areas where interaction with the wider team is limited because of COVID-19, at the time of writing.

9.2 Recommendations

Cage-based fish farming Research and Support for Decision Making/Planning

Cage-based fish farming is the sub-sector that is best placed to increase fish production for income security due to the higher intensity farming practices, the level of skills and financial assets of the farmers, and also the proximity to road infrastructure needed to transport fish products to markets. The road infrastructure also enables farmers to access feed suppliers, cold storage (albeit limited in PNG) and air strips. Cage-farming, however, can have severe environmental impacts in the absence of regulations, development guidelines, site selection criteria, and a knowledge of the carrying capacity of the waterbodies. Throughout Asia, where cage-based culture has boomed, the early stages of development were marred by water pollution, fish kills, disease outbreaks and social conflicts over access to water. There are lessons to be learned from cage-based farming in other countries. Our assessment of the state of farming in PNG, reviews of this sub-sector in other countries, involvement in lake-base farming research in other countries, and an evaluation of NFA's capabilities and need for capacity building indicate that the following are interventions are required:

1.) Site selection criteria for lowland and highland reservoirs to account for temperature differences (most of our research was in the warm temperate environments in the highlands; many farms are being established in the tropical zone)
2.) Scientific studies on lake limnology, lake classification and modelling to determine lake carrying capacity
3.) Farm-level guidelines on fish farming practices for lowland and highland systems eg fish feeding strategies, cage stocking densities, number of cage arrays per farm and maximum allowable farms per lake
4.) Research on feeds to improve fed conversion ratios, reduce environmental impacts, reduce costs, and improve consumption and digestibility of formulated feeds, and increase nutrient assimilation to optimise growth – again for lowland and highland scenarios (the current team has had experience on this in Australia and the Philippines)
5.) Business training for farmers
6.) Evaluation of feed and raw ingredient supply chains – this will be done under a proposed new project in collaboration with DFAT
7.) Food safety training to improve market price and protect human health
8.) Capacity building in environmental assessment to monitor for impacts and to feed data into carrying capacity models
9.) An overarching policy and development strategy for cage-based farming development in PNG to minimise environmental impacts and target interventions

These recommendations were endorsed by NFA and discussed with Dr Lino Tom.

Fish feeding strategies and feed formulations for higher intensity farming

Research on feed formulations for hatchery production of fingerlings is also required. Now that satellite hatcheries are being established around the country, NFA has requested research to test the cost effectiveness and most appropriate starter feed formulations for tilapia using locally-sourced feed ingredients. This request is being addressed under the proposed follow-on project. Similarly, fish feeding strategies are needed for scaled up production due to the higher stocking densities and need for changes in feeding frequency and feed formulations. NFA has indicated that reliance on imported feed is unsustainable and have requested that the follow-on project investigate developing locally-produced feed that optimises growth of tilapia and is less expensive than the imported feeds. This is request is addressed in the proposed follow-on project and will build on past work as well as UNSW's work on fish feed formulations for cage-based culture of fish.

<u>Growth performance of current broodstock families</u>

a. Whilst the new satellite hatcheries, if successful, will certainly alleviate the fingerling accessibility issues, fingerling quality via genetic and phenotypic quality, will still affect farm productivity issues. Hence, there is a need for research to determine the genetic quality of the current strain to see if it has maintained its initial performance characteristics or not and if possible, introduce new gene pool. As a baseline, further growth performance trials under the follow-on project would be beneficial and are part of the planned activities. As mentioned earlier, the growth performance during this project was considered good for small-scale farming. However, growth performance of the families was not tested under higher intensity systems or in cages.

b. Given the outcome of "a", NFA would consider importing whatever new and better performing strain that is available. Once imported, good management guidelines to maintain the genetic and phenotypic integrity of the strain, so it stays economically productive, will be needed.

<u>Satellite Hatcheries Work</u>

In addition to what is discussed above, NFA has suggested that a follow-on project can provide critical research support for its recently established satellite hatchery project. NFA has also requested that a follow-on project develop hatchery protocols for sex-reversal of fish to ensure best practice is adopted and for farmers to meet certification requirements. Protocols for handling, transportation and administration of SRT feed for sex reversal is required. Joshua Noiney, Jes Sammut and Jacob Wani have started to address this post project, but resources from a follow-on project are needed.

<u>Dissemination</u>

Instructional videos

The project team, through its well established network of farmers, NGOs, NDAL staff and Provincial Fisheries Officers, has effectively transferred knowledge across the country. However, many rural farmers cannot be physically reached for on-farm training. NFA has recommended developing instructional videos that can be transferred from farmer to farmer using Android phones. Despite the level of poverty, phone ownership in PNG is high. The Crawford Fund has supported UNSW and NFA to develop a small suite of videos ($5,000), and a private donor has provided $50,000 funds to UNSW to further support this endeavour and related activities in PNG, and potentially in other Pacific nations. We note that there are many parallels between PNG and tilapia production in other Melanesian countries ie the same species, similar practices and common farming challenges. There is an opportunity to adapt the better management practices for application in these countries. Science communication skills through video production is underway and will continue under a follow on project if supported. Jes Sammut and Alison Simmance are also arranging training in PhotoVoice under this funding to support future work and capture narratives from farmers impacted by the work so far.

Final workshop

Due to COVID-19 and NFA staff being busy with production of a strategic plan, a final workshop with NFA and other stakeholders was not possible. We have discussed running this workshop once travel restrictions are lifted, with costs covered by the UNSW Aquaculture Research Group and NFA. Nevertheless, Mr Jacob Wani has communicated the project findings to the NFA management team, the NFA Board, and recently with the Minister of Fisheries who was given a tour of project sites and NFA and ACIAR-funded project activities. Another alternative we are discussing is to run the workshop on-line given that the COVID scenario is unlikely to be resolved for some time.

Village of Hope Demonstration Farm

In the proposed follow-on project, the project team and UNSW staff will work with the Village of Hope in Jiwaka Province. The Village of Hope, established by the PNG Tribal Foundation and supported by Dr Lino Tom, is a model community with various livelihood options promoted. The team will contribute to the design of ponds, training of the community and working with women's groups organised by the PNG Tribal Foundation. This activity will create another information node and will also be potentially used by the Maria Kwin Centre for training activities.

Fish for Schools

Dr Lino Tom is eager to see the NFA Fish for Schools program benefit further from the ACIAR project inputs. He has recommended a nationally accredited package of skill building educational materials which would expand on what has been delivered by NFA and the project team. The proposed follow-on project will have team members from NFA coordinating this activity.

Continuation of Scientific Capacity Building

We reiterate the importance of scientific capacity building of the aquaculture unit staff. This is supported and encouraged by NFA, the Aquaculture and Inland Fisheries Unit, and Dr Lino Tom. NFA has requested UNSW and ANSTO to maintain capacity building if possible. Capacity building is also part of the NFA Corporate Plan and the new strategy. The project team has benefited from training which has enabled them to design studies, collect and analyse data (social, environmental, chemical and biological), and contribute to co-authorship of publications. Nevertheless, skill strengthening is still needed to enable project staff to apply skills to other aquaculture research, independent of ACIAR-funded projects. As for any science, skill building is a progressive process.

Joshua Noiney, a John Allwright Fellow, has commenced his studies at UNSW and has secured a top up scholarship from ANSTO's Graduate Institute. He is currently completing coursework and will commence the research component in September 2022.

There is also scope to transfer the capacity building and project findings to other Pacific nations as well as East Timor where farmers and scientists face similar challenges. NFA and UNSW have discussed possible South-South approaches, and also ways of raising PNG's visibility in Asia where many technologies could be adapted for PNG. ANSTO has also discussed opportunities to involve NFA in a training program coordinated by the International Atomic Energy Agency (IAEA). The program would build skills that would enable NFA to meet certification requirements for food safety. This program would provide opportunities under a proposed capacity building project as well as any follow-on inland aquaculture research eg to support modelling of lakes for carrying capacity.

UNSW and ANSTO will maintain their mentoring and capacity building role with NFA as part of the long-term collaborative relationship.

<u>NFA Strategic Plan and areas proposed for consideration in the next two decades</u>

The new fisheries strategic plan now proposes the following for aquaculture development which a follow-on project can contribute to.

a) **Establishment of Nucleus Estate type commercial/semi-commercial fish farming.** There is now a drive to transition PNG's aquaculture sector (near urban centres) to commercial levels, hence Nucleus Estate type operations run by individuals, large companies or cooperatives are proposed to drive commercial aquaculture. This aligns well with the proposed follow-on project which proposes research to address bottlenecks to scaling up semi-commercial operations. NFA is looking at establishing enabling infrastructure such as one-stop fisheries centers that will be serve as the main nucleus farm supporting all satellite farms. Our existing and growing network of advanced farmers will benefit this goal. Fish produced would be bought back less costs and then processed and marketed. This setup is proposed for Yonki Cage fish farmers, one in WHP and Chimbu Provinces – these are ACIAR project areas of activity.

b) **Research Stations** – The PNG Fisheries Strategic Plan recognizes the need for aquaculture research and has included the establishment of aquaculture research stations, preferably one mariculture (a second one after Nago), a brackish one and one more freshwater aquaculture. Accordingly, the proposed follow-on project can provide technical support to the freshwater aquaculture research stations, particularly through capacity building of staff and transfer of technologies.

c) **Training** – There is a clear need for additional staff with aquaculture technical capacity both in the interim and future aquaculture development in PNG. Areas that need training include;
    a. Aquaculture related Environmental Impact Assessment (EIA) for large scale developments such as prawn farms, large coastal cage culture developments and other farming systems. UNSW has undertaken such work in Indonesia through several past ACIAR projects, and recent collaboration with the Indonesian Ministry for Marine Affairs and Fisheries, and also trains government staff in EIA – this was planned for the proposed Capacity Building project.
    b. Large scale aquaculture project planning and management training – this is also an area of expertise at UNSW and was applied in Indonesia under past ACIAR projects.
    c. Specialized training in aquatic animal health, with the anticipated increase in aquaculture activities there is possibility of disease issues.

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Video (funded by NFA)

Farming Fish for change: https://www.youtube.com/watch?v=-osmL9-At4o