Chapter 20
Towards Food, Nutrition and Income Security in Papua New Guinea Through Inland Fish Farming

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Abstract Malnourishment and undernourishment are prevalent in Papua New Guinea, leading to disease, lower quality of life and less opportunity. Protein deficiency in diets is a pervasive problem in PNG. Inland fish farming was introduced as a means of increasing access to locally produced protein, particularly for rural people who are poor and most impacted by diet-related health problems. Over the last decade there has been rapid growth of fish farming attributed to development interventions that facilitate adoption of better farming practices. The high cost of feed, poor supply of quality fingerlings, lack of infrastructure, and limited access to technical knowledge are bottlenecks to fish farming that are being tackled by Government, NGOs and donor funded programs. Inland fish farming has also generated social benefits such as reduced crime and tribal fighting, introduced a second income for families, and increased access to better education and health services.

Keywords Genetically improved farmed tilapia · Fish farming · Human nutrition · Aquaculture · Protein

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20.1 Introduction

Papua New Guinea (PNG) is one of the oldest agricultural societies in the world. More than 87% of the population relies on subsistence farming, mainly vegetable growing, for food, (FAO 2017). Papua New Guinea is rich in natural resources such as minerals, fresh water, and fertile soils, yet more than 33% of the population earns less than $1.25 per day (FAO 2017). Fresh fruit and vegetables are readily accessible to most people in rural areas, with tubers a dominant component of diets. In contrast to subsistence vegetable farming, there is limited livestock culture except for small-scale chicken and pig farming which are widespread. Retail prices for fresh meat and fish are high for rural households. Pigs, although common, are usually eaten at ceremonies or used as 'bride price' in some communities (Anderson 2006). Consequently, consumption of protein is limited and affects the health of PNG's largely rural-based population (Asian Development Bank 2012; Gibson et al. 1991). High feed and transport costs also inflate poultry prices (Glatz et al. 2013), which is a disincentive to farm chickens at a scale that could help address protein shortages. The remoteness of many traditional communities in PNG, particularly in the highlands and small islands, and low per capita income (FAO 2017), limits access to retail sources of protein (Vira 2015).

Despite an increase in PNG's GDP, child stunting rates have increased since 2005 (Hou 2015). The prevalence of wasting (low weight for height- reflective of acute malnutrition) and nutrient deficiencies, such as iron, zinc, iodine, and vitamin A, are also high (Hou 2015). Paradoxically, although stunting of infants is common, particularly in the highlands of PNG, obesity becomes an issue for adults (see Chap. 4 for further details on a regional level of this paradox). The rising prevalence of obesity, diabetes, heart disease, and stroke threatens to encumber an already poorly resourced health system and will continue to have increasing impact on the morbidity and mortality of the people of PNG unless solutions can be found to provide adequate nutrition to all sectors of the community.

Having sufficient dietary protein is very relevant to a nation where the majority of adults are either overweight or obese. Insufficient dietary protein results in the overconsumption of fats and carbohydrates, as is the case in PNG. The problem with current staple foods in PNG is that they are low in protein and important micronutrients such as iron, zinc, iodine, and vitamin A (Hou 2015). Alternative food sources need to be found that provide higher amounts of these macro—and micronutrients on a per calorie basis without increasing the dietary content of saturated fat. This issue was recognized by Food and Agriculture Organization (FAO) in the 1950s during which a number of introduced fish species were stocked in rivers to create a wild fishery, followed by attempts to establish aquaculture.

Wild-sourced and farmed fish are now widely considered socially, economically, and environmentally sustainable options to increase protein in diets in PNG (Vira 2015). Fish farming, although not a traditional practice, has parallels to vegetable farming thus attracting interest (Hiruy and Sammut 2019; Tong 2018; Vira 2015). Unlike in Asia, where fish farming has a long history, fish farming in PNG has only

been practiced since the mid 1950s, and until the turn of the century was considered a small, fringe activity (Vira 2015). Although fish farming in PNG is increasingly adding protein to diets (Hiruy and Sammut 2019; Vira 2015), the inland aquaculture industry still faces the challenges of reducing production costs, improving farming skills in remote communities most in need of protein, and achieving similar production levels to farms in other parts of the world to enable farmers to generate income. For many farmers in PNG, low financial capital and a lack of knowledge on fish farming has stymied their efforts to maximize yields (Hiruy and Sammut 2019; Smith 2007; Tong 2018; Vira 2015).

This water, energy, and food nexus case study chapter focuses on a program of inland fish farming research and extension, primarily involving the authors, comprising a series of interlinked research for development (R4D) projects funded by the National Fisheries Authority (NFA) in PNG and the Australian Centre for International Agricultural Research (ACIAR). The research and extension program has concentrated on improving fish production through research on better fish feeding strategies, improved fingerling production and broodstock management, education of farmers, and creating information networks using established social systems to facilitate knowledge transfer. This chapter focuses on the impacts of extending research findings to farmers rather than outlining the details of research into the technological aspects of the program.

Firstly, the human health challenges that have underpinned the program's effort to increase fish in the diets of people in PNG are outlined. This chapter also provides an overview of strengths, weakness, opportunities, and threats to sustainable fish farming in PNG and how the R4D interventions, through partnerships with NGOs, farmer groups and government agencies, have increased access to protein and generated a number of positive social impacts beyond meeting the nutritional requirements of people (Wani et al. 2012). We use selected examples from the program's outreach and extension activities in both the highlands (Hiruy and Sammut 2019; Vira 2015; Wani et al. 2012) and coastal communities of PNG (Hiruy and Sammut 2019; Tong 2018) to demonstrate how fish farming can change lives by addressing protein deficiencies in diets, creating a source of income and improving the lifestyles of rural people.

20.2 The Human Nutrition Problem in PNG

There is a very high prevalence of nutritional disorders in PNG. PNG has the fourth highest rate of stunting (low height for age-reflective of chronic malnutrition) in the world, affecting almost one in two children under the age of 5 (International Food Policy Research Institute 2016). Despite an increase in its GDP, stunting rates have increased since 2005 (Hou 2015). The prevalence of wasting (low weight for height-reflective of acute malnutrition) and nutrient deficiencies, such as iron, zinc, iodine, and vitamin A, is also high (Hou 2015). Undernutrition in early childhood bestows an increased risk of rapid weight gain in middle childhood and obesity in adulthood (Gillespie and Haddad 2001). Thus, as individuals enter adulthood, the health burden shifts to one of overnutrition, with rates of obesity and type 2 diabetes rising rapidly in both men and women (ODE Review UNICEF 2013; Office of Development Effectiveness 2015). Nevertheless, while overnutrition is a problem, so too is the ratio of macronutrients in diets, with protein often too low to meet the daily requirement for adults.

The problems of under- and overnutrition are at great cost to PNG. Child undernutrition alone was estimated to cost $USD 508 million in the financial year 2015–2016, or 2.81% of its annual GDP, through its effects on child mortality, lost income and productivity, and the cost of treating diseases associated with childhood undernutrition (Hurney 2017). The rising prevalence of obesity, diabetes, heart disease, and stroke threatens to encumber an already poorly resourced health system and will continue to have increasing impacts on the morbidity and mortality of the people of PNG unless rapid solutions can be found to provide adequate nutrition to all sectors of the community.

20.2.1 Prevalence of Stunting and Wasting in Children Under Five

The prevalence of under-five stunting is extremely high in PNG at 49.5% in 2015—more than twice the world average. This represents an increase from 43.9% in 2005 (Global Nutrition Report 2020). Stunting rates are higher in rural versus urban populations, with the highest rates in the Highlands Region (61.5%) and the lowest in the Islands Region (38.1%) (Hurney 2017). Stunting affects boys more than girls and increases rapidly in both sexes from six months to 24 months of age before plateauing between the ages of two and five (Hurney 2017). While stunting rates decrease with increasing wealth, the rate is still very high in the highest wealth quintile (35% in 2009–2010), indicating significant non-fiscal influences on childhood nutrition.

The prevalence of wasting in PNG was reported as 14.1% in 2015. In contrast to stunting, the wasting rate was highest in the Islands Region at 29.2% (Hurney 2017).

Stunting and wasting are distinct conditions, reflecting chronic and acute undernutrition respectively. There is a stronger association between protein deficiency and stunting, whereas wasting represents a more general caloric deficit or a high incidence of infectious diseases, especially diarrhea (Bourke et al. 2016).

20.2.2 Effects of Childhood Undernutrition

There is a strong association between childhood malnutrition and mortality. Undernutrition results in a weakened immune system and increased susceptibility to infectious diseases such as diarrheal disease, intestinal parasites, and malaria (Bourke et al. 2016). Wasting is associated with a nine-fold increase in mortality (UNICEF 2013). Undernutrition has been reported to have caused or contributed to one third of child deaths in hospital (PNG Department of Health 2015) with estimates as high as 76% for childhood deaths under age five in community and health centres (Schmidt et al. 2019).

The first 1,000 days of life are believed to be crucial in determining the structure and function of a child's brain. Stunting impairs cognitive development and school performance. Cognitive damage is permanent and cannot be reversed with weight gain after the age of two (Martorell et al. 2010). Importantly, stunting has long-term effects on adult health. As stunted children enter middle childhood, a programmed metabolic shift occurs, resulting in propensity for rapid weight gain and the development of conditions such as obesity, hypertension, diabetes, heart disease, and stroke (Barker 1997; Gillespie and Haddad 2001).

The prevalence of metabolic diseases in adulthood is high in PNG (World Health Organization 2020). In 2016, 25.8% of women were obese and 58.1% were either overweight or obese. In men, 16.6% were obese and 47.4% were either overweight or obese. This represents an approximately 60% increase in the prevalence of obesity since 2005 (Global Nutrition Report 2020). Correspondingly, the rate of type 2 diabetes has dramatically increased. In 2016, diabetes affected 15.4% of men and 14.3% of women, representing an approximate 50% increase from 2005 (Global Nutrition Report 2020). Given the low rates of diabetes screening in PNG, this figure is likely to be a gross underestimation of the true prevalence of diabetes.

One in four adults have hypertension in PNG (Global Nutrition Report 2020). Whilst the prevalence of cardiovascular disease is not known, ischemic heart disease is the leading cause of death in adults (death rate 562 per 100,000 people), followed by stroke (198 per 100,000), with diabetes as the eighth leading cause of death (Global Health Index Data Exchange 2020; Centres for Disease Control and Prevention 2019) As obesity and diabetes rates continue to escalate, the burden of disease from metabolic non-communicable is expected to increase over the next decade.

20.2.3 Dietary Patterns in PNG

The traditional diet in PNG is low in protein and high in carbohydrates, with tubers or cereals, rather than meat or fish, providing most of the protein intake (Schmidt et al. 2019). Even today, locally grown plant food provides 76% of total food energy and 57% of total protein intake, whereas imported rice and wheat provide just 14% of total food energy and 17% of total protein intake (Bourke et al. 2016).

The staple foods of PNG are root and tuber crops, sago, and banana, the latter two being more common on the coast. The most commonly grown crop is banana, followed by yam, taro, and sweet potato. Other commonly consumed starches include cereal such as rice or maize, Chinese taro, sago, and cassava (Schmidt et al. 2019). Coconuts, nuts, and green vegetables provide a smaller portion of energy intake, but a relatively greater contribution to protein intake (Bourke et al. 2009) The main staple consumed is dependent on the region. For example, in coastal or riverine areas, there is greater consumption of sago, with limited vegetables (Hurney 2017). In urban areas, the staple foods are rice and wheat in the form of instant noodles and bread. More processed foods, such as tinned meat and fish, are consumed compared to rural areas, and over 90% of food is purchased from stores or markets (Government of PNG 2016). Nevertheless, the urban diet is still high in carbohydrates and low in protein (Bourke et al. 2009).

Meat and fish only contribute 6% of food energy but 25% of protein intake in PNG (Bourke et al. 2009). The most common animal products consumed are fish, shellfish, pigs (usually eaten at ceremonies), chickens, and cattle, although the cost of beef is often too high to enable regular consumption. Often, unhealthy forms of meat, such as fatty lamb flaps, are consumed (Muntwile and Shelton 2000). The type of protein consumed is dependent on local production and cost. Approximately half of rural households own livestock or have a fish pond (Schmidt et al. 2019). Pigs and poultry are the most commonly owned livestock, but in the absence of refrigeration, slaughtered livestock has to be consumed quickly (Vira 2015). However, in areas on the coast or near rivers or lakes, fish is the main source of protein (Schmidt et al. 2019) albeit not eaten often due to the high market prices or lack of fishing gear. On average, the people of PNG consume considerably less fish per person than in many other Pacific and Asian countries (Bourke et al. 2009) despite the abundance of water to farm fish, and in the case of coastal communities, access to many edible marine species.

20.3 Fish Farming in PNG

The abovementioned health issues have been a driver to increase access to protein in diets in PNG through inland fish farming. Inland fish farming is a commonly used aquaculture term for freshwater fish farming, whether conducted inland or in freshwater ponds close to the coast. Inland fish farming was introduced to PNG with the establishment of the Highlands Agriculture Experimental Station at Aiyura in the Eastern Highlands Province (EHP) in 1954, by the former Department of Agriculture, Stock and Fisheries (DASF) (Wani 2004). Initially, the focus was to farm common carp (*Cyprinus carpio*) using sweet potatoes and supplementary pelletized feed (Vira 2015). At the time, fertilization of ponds to drive natural food production was promoted as a suitable approach to feed carp, which are omnivorous, (La'a and Glucksman 1972; Reynolds 1970; Toneba 1980) as this was a low input farming practice thought to be suitable for poor farmers (Vira 2015). However, interest in fish farming was limited due to a lack of political support, higher than expected production costs and a lack of investment (Kan 1981). Government policy at the time also prioritized investment in production of plant-based protein (Wani 2004). A lack of traditional knowledge and expertise in fish husbandry (Glucksman and West 1963) also limited uptake of fish farming which was, at the time, a new farming practice (Wani 2004) and prone to failure.

A shift towards higher value trout farming occurred in the 1980s but this practice was limited to the colder waters of the highlands and considered an income generating venture (Vira 2015). However, trout farming, although still undertaken in PNG, never expanded with some farms closing due to community conflicts and farm mismanagement (Masuda et al. 1994). A small number of farms have persisted, but the production levels do not address food or nutrition security needs of PNG (Vira 2015).

Fish farming remained largely a low-input practice for decades that was not widely adopted. The lack of uptake of fish farming and unremarkable farm yields, due to a lack of fish farming skills, eventually resulted in the Aiyura station ceasing all fingerling production in 1985. The Japan International Cooperation Agency (JICA) interventions at Aiyura in the 1990s restored interest and support for aquaculture in the highlands. A JICA project was initiated in collaboration with the Department of Fisheries and Marine Resources (DFMR) to restore fish production at Aiyura. The department subsequently transferred the facility to the EHP government in 1998 when the DFMR became the National Fisheries Authority (NFA). The centre at Aiyura was renamed the Highlands Aquaculture Development Centre (HAQDEC) and although managed by EHP, research at the centre is mainly funded by NFA and operated by its staff, an arrangement that has continued. With fingerling supply at HAQDEC renewed under the JICA project, and increased extension and training, fish farming began to expand (Smith 2007). However, it was JICA's 1999 importation of the late-maturing and faster-growing Genetically Improved Farmed Tilapia (GIFT) (*Oreochromis niloticus*) (Gupta and Acosta 2004a) that accelerated the growth of

Fig. 20.1 Genetically Improved Farmed Tilapia (GIFT) is widely farmed in PNG. Households harvest fish as needed and excess fish are shared or sold with others thus increasing protein consumption in communities. Income from fish farming is invested in expanding farms, school fees, medical care, and household items (© J. Sammut)

aquaculture (Wani 2004) (Fig. 20.1). The species was easy to breed, tolerant of poor water quality, and could survive short periods of neglect by farmers.

The JICA project at HAQDEC ended in 2000. However, research and development continued through a series of collaborative projects funded by ACIAR and NFA. Through partnerships with Australian agencies, a long-term program of research and extension developed, driven by NFA and the University of New South Wales (UNSW) since 2009 (Vira 2015), and previously by the University of Western Sydney (Smith 2007). There are now over 60,000 farms in PNG mainly operating small ponds integrated into vegetable gardens, and most culturing GIFT, although carp farming still occurs as a monoculture or mixed culture with GIFT (Vira 2015). This case study focuses on GIFT production as it is the dominant farmed species in PNG (Hiruy and Sammut 2019).

20.3.1 Pond-Based Farming

Farming of fish in earthen ponds (Fig. 20.2) is the dominant culture system in PNG, mainly due to the lower technology requirements of farming fish in earthen ponds, and land availability (Hiruy and Sammut 2019; Smith 2007; Vira 2015; Tong 2018).

Fig. 20.2 A typical earthen pond system in Eastern Highlands Province constructed by a lead farmer. Most ponds are small and are integrated into vegetable or flower gardens (© J. Sammut)

The ponds provide a regular source of protein to households. Currently, there are two broad categories for pond-based farming based on level of intensity and farmer skills (Table 20.1, Sect. 20.3.2). Small-scale fishponds are constructed within or adjacent to vegetable gardens to utilize water that has been routed to irrigate crops. Integrating fish farming into the overall vegetable growing area helps to retain nutrients generated by the farms; pond effluent is discharged into the vegetable gardens, where it benefits crops.

The majority of farms in PNG can be classified as 'improved extensive' because farmers use only small amounts of formulated feed, mainly because of the high cost of fish feed, and do not use any mechanical aeration to maintain dissolved oxygen, as occurs in the higher density systems in Asia (Gupta and Acosta 2004a, b). Narimbi et al. (2018) found that the common practice of irregular feeding with fish pellets (usually weekly) is more cost efficient than daily feeding for ponds with low stocking densities in PNG; fish were found to utilize natural food for growth, and daily feeding using pelleted feed led to wasted nutrients and poor feed conversion ratios. By contrast, intensive pond-based systems used in other countries depend on mechanical aeration of ponds, regular water exchanges to maintain water quality due to the higher stocking densities, and high-grade, formulated feeds to achieve their high yields (Gupta and Acosta 2004a, b). However, although improved extensive farming of fish usually depends on low stocking densities, most farmers in PNG do not effectively manage in-pond fish breeding due to a lack of husbandry knowledge or a lack of effort (Hiruy and Sammut 2019). Consequently, unmanaged ponds become overcrowded

with the progeny of earlier stocked fish. Once tilapia reach reproduction age they may continue to breed, and this leads to higher feed requirements to maintain the growth performance of the fish. Additionally, water quality can deteriorate because of overcrowding.

To tackle the issue of overcrowding of ponds, lead farmers trained by NFA and the ACIAR project team have helped train other farmers to manage stocking densities by sexing fish and only farming males, which grow faster. However, this is a laborious and unwanted task, and the sex of tilapia cannot be determined until reproductive age is reached. To overcome this issue, NFA has trained farmers to produce and distribute all-male quality fingerlings. More recently, HAQDEC staff that were trained in hatchery practices in Asia (funded by NFA and Secretariat of the Pacific Community [SPC]) have successfully produced monosex fish (sex-reversed by hormone treatment to create all-male fingerlings) initially to support the ACIAR project's research and then for distribution to farmers. The sex reversal methodology is now being adopted by satellite hatcheries established by NFA. Since 2019, all-male fingerlings have become available through NFA's interventions thus eliminating the need to separate fish to prevent overcrowding of ponds.

Participating advanced farmers (Table 20.1) are often entrepreneurial, have better education, and have access to financial and social assets that enable them to invest in fish husbandry and quality fingerling production (Hiruy and Sammut 2019; Vira 2015). Subsequently, their yields are higher than for small-scale farmers (Table 20.1), and income generation is a priority over food security. Nevertheless, many small-scale farmers are improving their practices as a result of training and are aspiring to produce fish for supplementary income (Vira 2015). The program, through NFA, is currently developing strategies to enable more small-scale farmers to transition to an advanced level of farming; these strategies include widening the extension and training program, building the technical capacity of the Provincial Fisheries Officers to improve access to technical information, and informing NFA's development of a roadmap for aquaculture development.

20.3.2 Cage-Based Farming

Cage-based fish farming of tilapia (Fig. 20.3) is widely practiced in Asia, and was introduced to Yonki Reservoir, in EHP in 1994, five years after the reservoir was built. Initially the activity was not well received as the surrounding community preferred to exploit the wild fishery. Nevertheless, the stocking of the reservoir helped to provide protein to the communities surrounding the lake, as well as travellers along the Highlands Highway.

By the early to mid-2000s, wild fish stocks started declining due to unregulated fishing mainly through the indiscriminate use of various size gill nets that caught most age classes of fish thus reducing population recruitment (Wani 2004). The declining wild catches renewed interest in cage-based fish farming. By this time, the earlier access to wild fish had established a market chain for fish and an acceptance of fish as

Fig. 20.3 Cage-based farmers at Yonki Reservoir. Farmers have been trained by the project team and also supported under a previous SPC project. Cage-based farming utilises the water resources of hydro-electric reservoirs. However, there is an urgent need to develop management guidelines and carrying capacity models to minimise environmental impacts (© J. Sammut)

an alternative source of protein in communities that traditionally consumed pork—usually only during ceremonies—or other village livestock, such as chickens. A lack of quality fingerlings and access to feed, along with poor knowledge of fish husbandry, slowed the growth of the industry until NFA and ACIAR project staff, along with projects funded by SPC facilitated access to technology, knowledge, feed, and farm infrastructure. More recently, NFA facilitated the establishment of a hatchery at Yonki specializing in production of all-male fingerlings, which has alleviated pressure on HAQDEC to provide fingerlings to cage-based farmers. The success of the NFA-funded fingerling production training of lead farmers and project staff sent to the Asian Institute for Technology in Thailand, along with subsidized imported feed and nets in 2018, led to an increase in production (Hiruy and Sammut 2019). There is now a total of 77 semi-commercial cage fish farmers at Yonki Reservoir.

Cage fish farming at Sirinumu Reservoir, located in Central Province approximately 45 km east of Port Moresby, was introduced by NFA in 2003 after the landowners requested NFA to stock the reservoir with barramundi fingerlings to establish recreational fishing opportunities at the reservoir to bolster tourism. At the time, the sustainability of a recreational fishery was unknown, but the viability of cage-based farming was considered high due to the optimal water temperatures

for tilapia growth compared to the colder water of Yonki Reservoir, thus enabling farmers to produce more crops each year. NFA proposed and supported cage fish farming rather than recreational fishing given that food security was a priority and income could still be generated from cage-based farming. As for Yonki Reservoir, accessibility to fingerlings and feed are still the main impediments to farming at this location. With the establishment of two satellite hatcheries for sex-reversed (all male) tilapia fingerlings and availability of NFA subsidized feed, semi-commercial tilapia farming on Sirinumu is accelerating and surrounding areas, and residents of Port Moresby have benefited from access to fish-based protein. There are now 100 full time semi-commercial fish famers on the reservoir. Most of the farmed fish is either sold fresh at the farm site or cooked and sold in the nearby township of Sogeri.

20.4 Strengths, Weakness, Opportunities and Threats Analysis (SWOT) of Inland Aquaculture

The NFA-UNSW program of research has mainly focussed on clearing current bottlenecks to production, such as access to feed and quality fingerlings, and exploring the opportunities to grow the industry sustainably with food and nutrition security priorities over income generation. The program has utilized Sustainable Livelihoods and Lifestyle Analysis (SlifA) and several provincial and country-wide SWOT Analyses, along with various social impact assessment methods, to evaluate the status of the industry and to scope current and emerging issues to underpin NFA's strategic development processes. This section summarizes the findings of Vira (2015) and Tong (2018) and data from ACIAR Project FIS/2014/062 collected across eight fish farming provinces in PNG as a basis for strategic development of the industry by NFA (Table 20.1) and to inform the R4D program. Information from our active SlifA research (Hiruy and Sammut 2019) and data from interviews of lead farmers, farmer cooperatives, and staff of our project partners are also incorporated.

20.4.1 Strengths and Weaknesses

The strengths and weaknesses are largely internal factors that affect the sustainability of the industry. The tradition of farming is a key strength in PNG, despite the differences between growing fish and farming vegetables (Vira 2015). 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). 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 maximize yields (Tong 2018; Vira, 2015). Fish farming success depends on a supply of quality fingerlings, good fish feeding strategies,

Table 20.1 Tilapia farming categories and systems in PNG based on survey data collected by ACIAR Project FIS/2014/062

Farmer category	Goal	Average yield per ha per crop	Other characteristics
Small-scale (Subsistence farming)	Household protein needs followed by secondary income	< 50 kg/ha/crop	Usually dependent on fingerlings from others; low fish feeding frequency; vegetable garden waste as fish feed with limited supplementary commercial feed; pond fertilization to increase natural food Limited fish husbandry skills
Medium-scale (Advanced pond-based farmers)	Income then household protein needs	300 to 400 kg/ha/crop	Higher stocking and feed frequency; incorporate commercial feed or their own milled fish pellets; usually sell fish at markets; fingerling production has developed as a side business; better infrastructure and financial assets at outset
Cage-based farmers (Advanced)	Income then household protein needs	>1.5 tonnes/farm/crop	High stocking densities; entirely dependent on commercial feed; farmers have developed a short market chain; able to sell to retail sector but currently poor price negotiating power Currently practiced in Yonki Reservoir in Eastern Highlands Province and Sirinumu Reservoir in Central Province

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. The causes of stunting in fish include poor nutrition as a result of low-quality or expired feed, 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 2019; Vira 2015) but they are unable to distinguish which fish are stunted from 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. 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 2019). Interviewed farmers complained that fish feed, when available, was too expensive, or that they had no understanding of the feeding frequency required to maximize 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. Project survey data suggest that up to 40% of excess fish are shared with others in the community, thus making protein more accessible. However, farmers that 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 (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 utilize natural food (e.g., insects and algae), fertilizer to enhance primary production, and vegetables or crop waste to supplement the diets of farmed fish (Narimbi et al. 2018; Parata et al. 2020).

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 2019; 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.

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 (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). Later in this chapter, more detail is provided on how working with lead farmers and utilizing the wantok system has enabled fish farming knowledge transfer in PNG.

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. 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 2019).

20.4.2 Opportunities and Threats

Opportunities listed in Table 20.2 are currently being explored or have recently been 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 (e.g., amendment for the Fisheries Management Act 2015 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 subsidized feed while 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 ACIAR-funded projects, NFA is also investing more in farmer training programs for extension staff and farmers and transferring technical knowledge from research 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, utilizing the water resources of artificial reservoirs. With support from NFA and SPC projects, farmers have developed business plans and have been provided business start-up support. The ACIAR-funded 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 the team is shifting some of the research focus towards developing better management practices that minimize environmental impacts and maximize fish production. Similarly, the project team is 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.

A threat to food system security lies in that many of the raw ingredients for fish feed are utilized 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 subsidizing the cost for farmers. This approach is considered a short-term intervention. Accordingly, NFA is developing strategies, in partnership with the NFA-UNSW ACIAR-funded projects, to facilitate local feed production and to reduce the cost of feed ingredients for commercial and farm-based milling of pellets. The program of research is entering a new phase that involves breaking the dependency on imported feeds and to utilize 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 fish 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. Jealousy can often lead to sabotage, such as poisoning fish crops with plant-based toxins or chemicals. Early in the program, trout farms in EHP were affected by regular sabotage of stock to the point that some farms ceased operation. 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 2019; 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 the 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 it is postulated 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 (Jansen et al. 2019). 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.

Table 20.2 Summary of SWOT Analysis findings for inland fish farming based on a synthesis of information from Hiruy and Sammut (2019), 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 Utilization 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 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	Introduced fish diseases, particularly Tilapia Lake Virus Climate change Droughts and floods Theft of fish Sabotage due to rivalry and jealousy Competition for raw ingredients for fish feed Escalating feed costs 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

20.5 Generating Impact Through Fish Farming

This section discusses how the NFA-UNSW led program has generated impact in PNG using examples of our sub-programs and links to NGOs and other projects. The focus is on the social impacts from the extension programs rather than the scientific impact from the core research on fish nutrition and fish husbandry.

20.5.1 Utilizing Social Networks and Lead Farmers for Information Transfer

PNG has complex social networks (Baynes et al. 2017; Nanau 2011) that can be utilized to share knowledge on fish farming and nutrition. In PNG, the wantok system can often provide social welfare support utilizing well-established relationships, and trust and cooperation with other wantoks (de Renzio 2000). Accordingly, communities with a high level of social capital in PNG are likely to have greater capacity at collectively solving problems or facing new challenges largely through trust that facilitates sharing of time and effort (de Renzio 2000); thus, the social capital of a wantok can help new fish farmers to address the labour-intensive needs of establishing new ponds, as well as facilitating the sharing of new knowledge, fingerlings, and resources such as water needed to start farming fish (Vira 2015; Tong 2018; Hiruy and Sammut 2019).

With this understanding of wantoks, and the team and partner agency staff and NGOs belonging to various wantoks in the area of activity, it has been possible to promulgate new technologies and fish farming knowledge across PNG. Additionally, knowledge on the health benefits of consuming fish is shared. Earlier projects identified the importance of training and mentoring lead farmers (advanced farmers). These farmers were and continue to be identified and trained by NFA, the ACIAR Project team, other donor agencies and NGOs, to establish de facto fish farming trainers and advocates for better farming practices and promoting fish as a healthy source of protein. They also provide feedback from farmers on the partnerships' interventions, as well as helping to understand farmer needs. The selected lead farmers are often community leaders or have established a successful farming operation that has brought them status. Under the ACIAR projects, and through NFA's training interventions, advanced farmers are taught all aspects of fish farming, mainly site selection, fish husbandry, fish feed production, pond maintenance, harvest methods, and business management. As these projects produce new knowledge and technologies, the outputs are transferred to lead farmers who then disseminate the outputs more widely via their wantoks. Mentoring of lead farmers is undertaken by the project team and Provincial Fisheries Officers and facilitated by NFA's extension programs. Lead farmers are also trained and mentored by the project partners, for example, The Sisters of Notre Dame, a Catholic order of sisters who are embedded in the project. The Sisters of Notre Dame have combined fish farming training with their

missionary work in remote areas thus helping the umbrella program of extension, managed by NFA and the ACIAR project team, to extend its reach. The Sisters also promote the nutritional benefits of fish to children and adults. NFA also provides financial support and training to Provincial Fisheries Officers in major fish farming provinces, and also supports various NGOs that provide livelihoods training.

20.5.2 Formal Training

The Sisters of Notre Dame, at the Maria Kwin Training Centre in Jiwaka, also deliver certificate-level fish farming training to lead and other farmers, as well as training women ostracized from their community due to sorcery accusations or have fled because of domestic violence (Fig. 20.4). The Maria Kwin Centre also formally trains former drug addicts, single mothers, delinquent youths, gang members and people, who have faced financial hardship, to create a livelihood. The Sisters also use fish farming in their Personal Viability Training Program, a formal program that aims to build self-respect and self-esteem, improve gender relations, reduce violence against women, and develop positive social behaviour. The NFA National Fisheries College in Kavieng also provides certificate-level training with selected farmers sponsored by NFA to attend courses at the College. Selected lead farmers have also been trained by SPC projects, and some sent to Asia to receive training in specialized areas, such as hatchery production of fingerlings. The ACIAR project team also coordinates formal training programs for NGOs and farmer groups.

Through NFA, these project technologies and farming knowledge are also transferred to Provincial Fisheries Officers who provide further technical support to farmers. For example, trained Provincial Fisheries Officers, including staff embedded on the project, have established satellite hatcheries and fish farms in Morobe Province where they also coordinate training programs and are working with the local prison to establish fish ponds. However, the lack of resources and funding issues limits the ability of trained Provincial Fisheries Officers to undertake field activities (Hiruy and Sammut 2019; Tong 2018; Vira 2015); this is issue is being tackled by the NFA through a roadmap for strategic development of inland aquaculture in which increased support for Provincial Fisheries Officers is flagged as a key intervention.

20.5.3 Fish for Schools Program

The Fish for Schools program was established by the National Fisheries Authority of PNG to develop an interest in fish farming as a future livelihood option in youths, to build fish farming skills for high school students unlikely to continue to tertiary-level study, and to enable teachers to use fish farming to support teaching. Teachers, for example, use the fishponds to teach human nutrition, ecology, biology, physics, mathematics, economics, agriculture, and physics. Technical information is provided

Fig. 20.4 A training day at Warala Village in Jiwaka Province. In partnership with local lead farmers, the Sisters of Notre Dame and the NFA team members conduct certificate level training enrolled at the Maria Kwin Centre as well as using locations like this to train farmer groups (© J. Sammut)

by the NFA staff and draws on training in fish husbandry developed under the ACIAR and NFA-funded projects. As farming technology from the research projects becomes available, it is transferred to the Fish for Schools program. Additionally, the program has provided access to fish in school canteens, raised awareness of the nutritional value of fish, and facilitated knowledge transfer to nearby communities, mainly through school children sharing knowledge with their parents and partly through the presence of the fish farms on school campuses; the fish farms have drawn interest in fish farming in the wider community.

20.5.4 Fish for Prisons Program

The Fish for Prisons program was initiated by NFA in partnership with the PNG Correctional Services. The primary goal of the program is to build skills in fish farming for prisoners to provide a livelihood option for their release. For many prisoners, re-entering the workforce is challenging due to the stigma associated with a criminal record and a lack of skills. Released prisoners lose status in their community and are often alienated. Without an opportunity to earn income or draw on the support of their community, the risk of re-offending is high. From the outset, it was

theorized by the founders of the program that skills in fish farming could break the cycle of crime and repeated incarceration. Furthermore, the program was designed to build self-esteem in prisoners, which is often already low before incarceration and made worse by being kept away from family and communities during their term. Through involvement in this NFA program, the project team has worked alongside prisoners through training activities and by mentoring them through all stages of fish production. This process has built trust between the NFA, the project team members, and the prisoners, facilitated information exchange, and built a rapport with prisoners that has been critical to improving their feelings of self-worth and restoring their dignity. Most released prisoners have also maintained communication with the project team, seeking technical advice and mentorship. The prisoners construct the ponds, manage the water supply, stock, feed fish, monitor the health of the stock, and conduct day-to-day pond maintenance such as clearing weeds, repairing pond walls and canals, and evaluating the condition of the fish. The prisoners also harvest their fish for the prison kitchen thus providing access to much needed protein. The themes of hope and restoring dignity are regularly communicated by the prisoners to the project team.

Gaius (surname withheld), serving a 28-year term, speaks of how fish farming has given him hope and will one day enable him to become 'somebody':

> *When I came to prison I thought I have no choice or I have no hope. I think I will just stay here in prison, and when I release (sic), I go back. I have no choice (future choices), because I am in prison and everything is gone, and I will just go and stay a poor person. I am happy that when I finish, when I release (sic) from prison, and I go back to my home, I'll do that job (fish farming). I'll try and look after fish because my area has many good rivers, many good creeks from the mountain to valley, so I can dig some fish ponds and look after fish, so I get some knowledge (from the training program), and then go back to my home, I'll become somebody.*

In other interviews, Gaius and his peers mention aspirations to seek formal qualifications in fish farming from the NFA National Fisheries College in Kavieng or at the Maria Kwin Centre in Jiwaka Province. Other prisoners have shared similar stories of hope and wanting to be 'somebody' again, despite their long prison terms. Each prisoner's narrative describes fish farming and the associated training as a means of addressing idleness, improving their mental health, and setting goals for the future. *"We have proven that we can grow fish. Fish is food now and tomorrow, and fish will become kina (local currency) when I am released. People see me again and now I am a good man again,"* (unnamed prisoner, Bihute Prison). Most significant is the reference to fish farming restoring dignity and having a skill to be proud of, often conveyed to our team with emotion. The change in the temperament of the prisoners is also voiced by the prison staff who consider the program to have reduced disruptive behaviour within the prison.

Prison Officers, who have worked alongside our team and the prisoners, have also built skills in fish farming and some have incorporated fish farming into their retirement planning. Under our previous project we also conducted similar training with retiring military staff to provide a livelihood post-government service. Currently, the Fish for Prisons program has involved men's prisons, but plans for extending

the program to women's prisons are under consideration by NFA and the PNG Correctional Services.

The project team has also mentored and monitored prisoners following their release from prison, including some who were released over a decade ago and who have now fully regained status in the community and become lead farmers. To the best of the project team's knowledge, and based on the records of participating prisons, former inmates who were trained under the program have not re-offended. Fish farming has provided an opportunity to demonstrate to their communities their capacity to apply themselves to a livelihood rather than to be seen as a probable re-offender. Over time, the success of fish farming draws interest from others, and sharing of knowledge and excess fingerlings have helped to restore dignity in ex-prisoners and elevate their status.

Moxy (surname withheld), is a long-term participant of the program. Trained by NFA at Bihute Prison during his prison term and released over a decade ago, Moxy is known locally as "Daddy Fish", which is not just a light-hearted nickname, but a name that reinforces his status as a lead farmer in his district. Moxy is both amused and proud of this nickname, with the pride clearly of more importance as he communicates to his mentors from our team of the significant positive impact of fish farming. Following his release from prison, Moxy built his own ponds in the shadow of scepticism from his community but with supervision from NFA staff based in nearby Goroka. At the time he was still seen as a criminal outside of his family and close friends thus having limited access to the community's social capital, principally labour to dig ponds and financial support. He was successful at establishing ponds and producing reliable crops, and this drew attention from other fish farmers and people interested in building fishponds. Within several years of establishing his own farm, Moxy's ponds became an unofficial demonstration site, and he became an advocate for fish farming, and a lead farmer and trainer under our program. His status was renewed, and in his opinion, it was higher than before his incarceration. His fish farm business, which also involves his wife and adult children, provides sufficient income to maintain the household, and to access better medical services and education for his school-age children. Moxy describes how his fish farm has enabled him to live an honest life:

> *Sometimes, when I feel could do wrong again, I come down to my fish farm and I look at what I have achieved. It brings me peace. It stops me from doing wrong. Working with fish calms me down and I feel proud of what I have created.*

This feeling is sentimentally repeated to the project team by Moxy during site visits, and similar remarks are heard from former raskol gang members. Moxy's community peers also mention the transformation in Moxy since his release from prison and speak of the inspiration gained from seeing his success. Since his release from prison, Moxy has worked alongside the ACIAR project team at farmer field days and other events where the project team conduct extension support to farmers. His role as a communicator of knowledge and a champion for fish farming has led to more farmers adopting technologies and practices developed by the NFA and ACIAR-funded projects.

20.5.5 Working with Raskol Gangs and Tribal Fighters

Raskol is a PNG term for gang members who are known for violent crimes. Raskol gangs are usually active in impoverished areas, particularly in remote areas where police resources are limited. Raskol gangs are also active in and around the settlements in major urban areas such as Port Moresby and Lae. The NFA and ACIAR-funded projects include project partners that operate in areas where raskol gang activity is prevalent. Raskol gangs have participated in fish farming training delivered by the project team to farmers in the highlands, and also via the Sisters of Notre Dame who have outreach programs in remote areas. As a result of skill building, and the positive social interaction between the extension staff and gang members, Raskol gang members have developed a better appreciation of their worth to their community and society. The responsibility and rewards from fish farming have increased self-esteem and enabled former gang members to set goals and develop strategies to develop their farms.

> *Fish farming gives them purpose and helps them to redeem themselves and to atone, and this enables acceptance by the community. They don't want to be seen as gang members once they realize what they can achieve through fish farming. It is their ticket back to society.* (Sister Pauline Kagl, Sisters of Notre Dame)

Of note is the impact of fish farming training on crime reduction along the Highlands Highway, the only roadway that links the Highlands to the coast. In areas where fish farming has been adopted, villagers have reported a decline in crime committed by raskols, as well as reduced youth delinquency (Sister Pauline Kagl, Sisters of Notre Dame, personal communication). The 'Barola Hotspot', a short stretch of the highlands highway near the major township of Kainantu in EHP, was well known for carjacking, rapes, roadside robberies, and other violent crimes against travellers. Through fish farming training conducted by the project team, raskol gang members abandoned their criminal activities at this location. Their participation was uninvited, but they were drawn in by curiosity and accepted into the training program. Within a year of training, the participants had cleared marijuana crops to construct ponds, contributed to the construction of ponds for the community, and also helped to establish a fish farming training centre in partnership with the local community and government. Joe Alois, staff of NFA and a trainer under our program noted:

> *At the launch of the aquaculture training centre at Barola, the former raskol gang burnt drugs and weapons to demonstrate a commitment to a new life. Since the training, the Barola Hotspot has been free of violent crimes. We mentor the former raskols, who we now treat as fish farmers and ensure they have the technical support to keep succeeding.*

Similar reduction of crime along the Highlands Highway has been attributed to the training provided by the project partner, the Sisters of Notre Dame, and also by lead farmers trained under NFA and our extension program (Hiruy and Sammut, 2019). Interviewees reported that fish farmers depend on social networks and that raskols must work harder to be accepted back into a wantok; initially, this is a challenge for raskols, but their contribution to pond construction helps to foster acceptance

by the community (Sister Pauline Kagl, Sisters of Notre Dame, personal communication 2018). The responsibility and comradery needed to develop farms and share resources, reduces the idleness that underpins anti-social behaviour. Nevertheless, social problems such as jealousy and subsequent sabotage of farms, as well as theft of stock, remain a problem (Vira 2015) and are difficult to address.

20.6 Conclusion

Fish farming has had demonstrable positive social impacts in PNG. Although this research program has focussed on clearing technical bottlenecks for fish production to improve access to protein, the unexpected social impacts of working with lead farmers and farming communities have demonstrated the wider benefits of aquaculture in PNG. Investment in training and mentoring lead farmers, partnerships with NGOs, and utilizing wantoks as knowledge networks has not only enabled the spread of fish farming knowledge—it has led to broader access to protein, particularly in remote rural areas, and improved food security. The accelerated growth of fish farming and its social, health, and economic benefits, has revitalized government support for the industry as demonstrated by recent amendments to the PNG Fisheries Management Act (2015) to include aquaculture objectives. This collaborative program is expanding to develop new strategies for aquaculture in PNG based on the technological outputs and the now well-established knowledge networks and partnerships with stakeholders. The NFA Aquaculture and Inland Fisheries Unit, the major local partner, is now well positioned to develop strategies to help transition small-scale farmers to higher intensity practices, and to facilitate access to affordable protein in urban areas via fish supply from cage-based farmers. The described recent research breakthroughs on fish nutrition and the production of quality fingerlings, and NFA's success in establishing satellite hatcheries, have cleared significant bottlenecks. The greatest challenge is to resolve issues with the supply of cost-effective formulated feed to support the emerging cage-based farming industry and the transition to higher intensity pond-based farming. If aquaculture production levels can reach those of nearby Asian countries, many of the health issues associated with low protein in diets can be alleviated.

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