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Applying one health methods to improve cocoa production in Bougainville: A case study

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ABSTRACT

Cocoa production is the major contributor to livelihoods for farming families that constitute nearly two-thirds of the population of the Autonomous Region of Bougainville, a Province in Papua New Guinea (PNG). These families, living mostly in subsistence poverty as a result of the Bougainville Civil War (1988–98), have significantly reduced cocoa production. Efforts to rebuild the industry have not been realised, due to known agricultural factors such as labour shortages, pests and diseases, poor support for farmers from trained agricultural extension officers and inefficient cocoa supply chains. But cocoa production involves factors other than agricultural ones. This article describes how we applied One Health methods to design and undertake a 6-year research project in Bougainville to improve cocoa productivity. Maximising the health and wellbeing of farming families and increasing agricultural productivity we argue, requires an in-depth understanding of the non-linear interactions between health, labour, household decision-making, yields and incomes.

1. Introduction

The Autonomous Region of Bougainville (ARoB), a province of Papua New Guinea (PNG), faces significant constraints to economic growth and human development caused by the destruction of infrastructure during a civil war between 1988 and 1998. The 2016 Human Development Report ranked PNG 156th out of 187 countries on the Human Development Index [2]. Approximately 40% of the Bougainville population of 249,358 [3] live on less than \$1.25 per day; with an average life expectancy of 63 years and high rates of malnutrition. A 2016 Save the Children report estimated that, during the 2015–2016 financial year, undernutrition cost the PNG government \$USD 508 million due to losses in productivity and income from poor health [4].

While cocoa production is the main source of support for nearly two-thirds of the ARoB population, cocoa production and profitability have been falling since 2009. Before the civil war, almost 28% (approx. 15,600 t) of Bougainville's annual cocoa production came from large plantations [5] which were abandoned during the conflict. Smallholder production collapsed, impacting on the livelihoods and wellbeing of thousands of farmers and their families. Trees planted during the

reconstruction after the Crisis are generally poorly managed resulting in declining yields. Efforts to increase production through conventional farmer training have had minimal success. This is partly explained by poor implementation of training but the reasons for that are poorly understood.

Our research aim is to enhance the quality and profitability of cocoa for smallholder cocoa farming communities in Bougainville using One Health interventions that improve the health and wellbeing of the cocoa farmer, cocoa tree and the environment. This article is a case study in applying an integrated One Health approach to improve cocoa production in Bougainville. It describes how our transdisciplinary team, in partnership with the ARoB government designed and implemented research to better understand the challenges facing cocoa farmers and improve the profitability and vitality of smallholder farming families and communities.

2. Agricultural approaches

Increasing cocoa exports is core to the ARoB plans for economic recovery as cocoa is the main source of current and future employment

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Table 1

Using a One Health Research Framework for investigating low productivity of cocoa farmers (this conceptualisation used the framework developed by Lebov et al. [22]).

Farming factors	Potential environmental factors	Potential animal factors	Potential human health factors	Potential human behaviour/susceptibility factors
Cash crop (cocoa, copra) production	Farm management	Domestic animals	Malaria	Poor adoption of improved production methodologies
Food crop production	Water sources	Pigs	Disease vectors (mosquitoes)	Few incentives to increase production
Farm management skills	Soil degradation	Chickens	Tuberculosis	High price volatility
Income diversification	Deforestation	Wild animals	Respiratory diseases	Fortress crop (crops for cash when needed)
Number and size of blocks	Forest conservation	Loss of animal habitat	Communicable diseases	Labour shortages
Market knowledge	Food security	Extinction	Non-Communicable diseases	Poor education
Pests	Climate uncertainty	Food sources	Other chronic conditions (Diabetes)	Poor access to government services (health, education, agriculture and veterinary)
			Lack of medications	Poor roads
			Lack of health professionals	Poor transport systems and market access
			Lack of health services	Low borrowing capacity (Banks)
			Prevalence of Domestic violence	Poor housing conditions
				Unimproved water sources
				Unimproved sanitation
				Proximity to animals
				Food insecurity
				Nutrition insecurity
				Women's roles
				Cultural norms (births, deaths)
				Beliefs (health, food, witchcraft)
				Religion

Many uncertainties relate to low production of cocoa – A One Health methodology explores the possible factors associated with poor cocoa production. Factors in **bold** are new One Health factors

While this is not a comprehensive list, it identifies the key areas that arose during discussions with the research team and workshop participants.

and income. Higher incomes for farming families and the Government have the potential to bring sustained improved health and education opportunities for farmers. Constraints on productivity improvements include poor crop and soil management, crop losses due to pest and disease infestation, substandard fermentation and drying causing variable bean quality, poor market linkages, poor transport, a lack of extension support, and shortages of labour.

The delivery of cocoa extension programs is currently fragmented and focuses on conventional integrated pest and disease management, crop husbandry, plant protection and soil fertility management. These agricultural components are necessary but there is no evidence that these interventions alone improve productivity or livelihoods.

We know that sustainable economic development requires long-term broad-spectrum interventions that simultaneously address community, gender, health, environment, infrastructure and economic constraints [6]. Underpinning the 17 Sustainable Development Goals (SDG) is the recognition that poverty cannot be addressed by a singular focus [7,8]. Rather the SDG agenda requires a more holistic approach; one that appreciates the many complex health and livelihood issues that surface in the relationship between humans and the ecosystems in which they live [9].

We suggest one reason why agricultural development has limited

impact in low resource countries is a narrow 'agricultural' focus which routinely excludes considerations of household priorities and key economic, environmental, social or human health constraints. Developing programs that maximise the health, wellbeing and agricultural productivity of farming households requires an in-depth understanding of the non-linear interactions between health status, labour availability and inputs, household decision-making, yields and income [10]. Women, for example, play a vital role in linking agricultural production, human health and nutrition because they are primarily responsible for food preparation and caring for children and sick family members, and in some cases, are the main agricultural producers. Women, though, typically have limited access to productive resources, financial skills, markets and are often constrained by household roles [11]. Empowering and engaging women in agriculture can improve their access to income and resources, which can then lead to improvements in household health and nutrition [12].

Understanding and addressing such complex, multi-faceted issues requires holistic systems-based thinking and transdisciplinary collaboration.

3. A one health approach

The role of the environment on health and disease, shaped by the cholera outbreaks starting in 1831, gave birth to hygiene theory and environmental health movements [13]. In addition to recognising zoonotic origins of infectious human diseases [14], researchers have widened the lens to focus on the health and wellbeing of humans, animals, plants and the natural environment they inhabit [15].

One Health transcends disciplinary boundaries, by promoting cross-pollination of ideas and systems thinking, and applies the following key principles – stakeholder participation, transdisciplinary collaboration, sustainability, gender and social equity and translating knowledge into action [16]. Although the term in recent times has been linked to zoonotic diseases, One Health is broader and tackles development issues that sit at the interface between humans, animals, plants and their environments, bringing together disciplines and expertise that have traditionally existed in discrete silos. Such collaborations can impact on the quality of livelihoods and local and national economies [17]. While there is consensus that these collaborations foster innovative solutions to complex problems, there is limited literature available on how transdisciplinary approaches are applied in practice [18]. This article describes the application of a One Health approach to improve cocoa productivity in Bougainville.

The One Health approach has been widely endorsed and accepted by international organisations [19], but has been criticised for its heavy focus on the biological transmission and clinical aspects of diseases and failure to incorporate the underlying environmental, social and contextual factors that also influence behaviours and health outcomes [20,21]. In response to these critiques, One Health Frameworks have been developed to assist in the conceptualising of One Health approaches [19,22]. Our study used a framework developed by Lebov et al. [22] to identify key factors underpinning production of cocoa within Bougainville. This was achieved through a workshop held in Bougainville in 2016 with the research team, the research partners (ARoB) and invited participants (Government department staff, farmers, women's groups, farmer cooperatives, community leaders). Using a One Health framework [22], we can predict that intersecting factors such as food insecurity, poor health, unsafe water, vector-borne diseases, sanitation practices, health services, labour shortages, poor infrastructure, transport systems and climate change are likely to impact on smallholder cocoa production [4] (Table 1).

The interdependencies between humans, animals and environments [15,23,24] have underpinned public health advances since the 19th century but One Health research takes the concept further by

investigating interdependencies of these factors with soils and plants, and putting the findings into practice. One Health principles (Table 2) and methods underpin this 6-year research project funded by the Australian Government 'Developing the cocoa value chain in Bougainville' [25].

Disciplines such as agriculture, health and nutrition have traditionally been siloed, ignoring clear links. Surprisingly, while labour constitutes half the cost of production of smallholder cocoa, agricultural research has rarely factored in the impacts of human health status on productivity. Similarly agricultural processes have rarely been factors impacting the design and implementation of community health and nutrition initiatives [26].

This analysis used systems thinking to better understand multi-directional linkages between the livelihoods of cocoa farmers and their health and nutrition. Our method of integrating health and nutrition goals into agricultural system development projects anticipates that productivity and sustainability of agricultural systems will improve but also maximise contributions to the health and wellbeing of communities [12].

4. One Health research design

One Health research typically has four phases: Participatory design phase; Knowledge development phase; Intervention strategy phase and the Systematisation phase [27]. The phases are not sequential with the research moving back and forth, adapting to new situations as required. First a transdisciplinary team was established in recognition of the multi-diverse and multi-directional factors that have the potential to impact on productivity and cross several disciplines of agriculture, health, nutrition, veterinary science, culture and economics. Poor-health impacts on the ability of a farmer to tend their crops or poor crops may be caused by poor management processes. Cultural obligations may impact on food security and cocoa tree management. For example, the practice of Haus Krai involves the whole community providing food for a family in mourning; a practice that can last as long as a week or more depending on the person who died. Access to markets may impact on a farmer's ability to generate income, afford food and healthcare.

A collaborative research team comprising the University of Sydney (Schools of Life and Environmental Sciences and Public Health), the Australian Centre for International Agriculture Research (ACIAR) and a number of in-country partners including ARoB Department of Primary Industries, and the Department of Health, PNG Cocoa Coconut Institute and the PNG University of Natural Resources and Environment was

Table 2
One health principles [27].

Systems thinking	A systems approach considers the relationships among the different elements. For example: Cocoa farming system: soil & environment/ land availability/climate/farmer capacity (health & nutrition, education, income)/labour/crop management/ production/markets/transport infrastructure/cocoa sales Market system: producers/buyers/consumers/infrastructure/ industry/regulations/technology/information/informal markets Health system: Service delivery/health workforce/ health information/accessibility/ medical technologies/ health financing/ leadership & governance Food system: production/ processing/ packaging/ distribution/ marketing/ consumption
Transdisciplinary research	The team is made up of those with knowledge representing different scientific perspectives, integrated research methodologies and tools across multiple disciplines as well as those with lived experience of the situation being investigated- cocoa farmers/village leaders, household heads/local government.
Participation	Engaging the stakeholders (Village Assemblies, leaders, Government departments, outreach services, NGOs) throughout the research helps resolve conflicts, reduce barriers, solve research dilemmas, ethical problems, dissemination of information, and more.
Sustainability	The interventions are environmentally, culturally and socially sustainable and capable of enduring in the long term, but change may not be as expected. Understanding the enablers (strong leaders) or impediments (extreme poverty) in a community will give greater depth to understanding how change occurs in a given place or community.
Gender and social equity	One Health addresses unequal and unfair environmental and social condition that negatively impact on women and children who frequently suffer ill health, malnutrition and levels of violence.
Knowledge to action	Managing the tension between research and improving livelihoods is part of One Health endeavours. This means documenting pre-existing conditions and the changes during the interventions. Knowledge translation bridges the 'know'- 'do' gap and is a continuous changing process that analyses, disseminates and exchanges knowledge attentive to ethics and culture.

established to work with communities (farmers, village leaders) using a transdisciplinary approach. With the transdisciplinary team in place, the research followed the four phases outlined below in relation to improving cocoa production in Bougainville [27].

5. The participatory design phase

The Bougainville Civil War saw the destruction of most government and public infrastructure. The ARoB Department of Primary Industry, which is responsible for the redevelopment of agricultural industries on the island became a partner, with the departments of Health and Local Government joining as informal partners. In addition, team members held meetings with other key stakeholders and met with village representatives to discuss their priorities. Drawing on existing networks, a preliminary community consultation was held between a local cocoa cooperative comprising several villages and researchers from the University of Sydney in Malassang, Buka in 2014. During this meeting, community leaders requested support in their efforts to improve their livelihoods through the key areas of health, education and improving the value of their cocoa. Two public health female members of the team also separately met with village women to identify their main challenges. In addition, a series of multi-disciplinary meetings and individual meetings were held with local leaders, women and youth to ensure the project was appropriate to their needs and that realistic strategies were designed to meet them.

The preliminary scoping of the problems/challenges facing cocoa farmers on Bougainville were then discussed and debated within the research team leading to the development of HORT/2014/094 Developing the Cocoa Value Chain in Bougainville – a 6-year project managed by ACIAR funded through the Australian Aid Program [25]. Table 3 lists the four project aims and associated research questions.

A three-day (3–5 February 2016) meeting with attendees from the ARoB government, NGOs, district and village representatives was held in Buka. The agenda was structured with plenary sessions by key stakeholders and the research team with small group discussions to hone research plans and give feedback during plenary sessions. A Workshop report was produced and circulated. Achieving gender equity in representation at the workshop was a challenge notwithstanding that Bougainville is a matrilineal society where land ownership is mostly passed through the women. Women played a major role in the peace agreement and continue to play a major role but with the demands of the household, children, gardens and selling vegetables at the market women find it difficult to make the time for additional activities.

Following the stakeholder workshop, a governance structure was implemented consisting of Government, District, Village Assembly and village levels. Annual meetings are held with the different levels of administration. The research team meet with stakeholders annually and with more engaged stakeholders on a case by case basis. Updates on the research activities are provided and challenges discussed. Work around options are agreed upon when a situation demands it. Project groups using platforms such as WhatsApp and Facebook have been established to facilitate ongoing consultation between stakeholders and provide project updates to a wider community. The Facebook page is moderated

by an in-country project team member and currently has 98 members over half of which are women. Local farmers have been invited to engage in this group, however due to limited access to electricity, poor internet connectivity and low mobile phone ownership, many are unable to. Information is shared to the villages through appointed hub managers and village extension workers (VEWs). Participatory stakeholder engagement including with the villages is a key principle of a One Health approach, and central to this project [28]. To maintain community involvement in decision-making and implementation of project activities, advisory committees were established in each region. The committees, attended by village leaders and representatives from women, youth, cocoa farmer groups and members of the project provide leadership for developing the regional hubs and Village Resource Centres (VRCs). Discussions with Australian-based project staff, communities are given the option of using English or *Tok Pisin*.

This project encourages women to participate and lead extension, education and capacity building activities based in the VRCs on topics covering agriculture (cocoa management and processing, supplementary crops, food crops, small livestock, budgeting, market access) health (water, sanitation, vector borne diseases) and nutrition (diets, vegetable crops). The emphasis on a family team approach to farming intends all adults and youth within the family unit engage in farm management and allocation of resources/assets [11].

6. Knowledge development phase

Each research aim had a range of interventions designed to answer the research questions. One of the first activities was to conduct a cross-sectional baseline livelihood survey that captured data including geopolitical factors, economics, populations, livelihood strategies, housing standards, education, nutrition, food security, healthcare, access to mobile phones, banking, farm sizes and enterprises, details of farming activities (number and age of cocoa and other trees, management, yields, fermentation and drying, marketing, etc.), food crops and livestock. The questionnaires were drawn from existing validated survey tools (UNICEF MICS, USAID DHS, WHO World Health Survey and surveys covering cocoa production, pests and livestock were adopted from two previous surveys administered by ACIAR projects ASEM/2006/127 and PC/2012/051. Questions were contextualised and modified after piloting and translated into Tok Pisin.

The main research advisory committee finalised the sampling principles and agreed on the recruitment process to hire 30 interviewers (10 for each region with an equal number of male and female interviewers). Initially more men than women were selected requiring the recruiting team to remedy the gender disparity. A total of 33 Village Assemblies (VA), Fig. 1 from each region were purposively selected using a list of principles detailed in Box 1. All households within the selected VA's were eligible for interview. Households were given information about the project and survey by their local extension officers prior to data collection.

Trained interviewers administered the survey at households using a mobile data capture application (CommCare) on Android Tablets. Verbal consent was obtained from participants at the time of interview.

Table 3

Research aims and questions for HORT/2014/094 developing the Cocoa Value Chain in Bougainville.

Research aim	Research questions
1. Improve the productivity, profitability and sustainability of cocoa farming and related enterprises	<i>Among the many technologies available for intensification of cocoa production, which options and combinations are most appropriate to the social and biophysical context of Bougainville?</i>
2. Understand and raise awareness of the opportunities for improved nutrition and health to contribute to agricultural productivity and livelihoods	<i>To what extent is poor health and nutrition a barrier to improved agricultural labour capacity and living standards?</i>
3. Foster innovation and enterprise development at community level	<i>Can public sector R&D investment catalyse enterprise development leading to diversified and stable incomes and improved social outcomes for cocoa farming families?</i>
4. Strengthen value chains for cocoa and associated horticultural products.	<i>How can market access and value chain efficiency for cocoa and other farm and garden outputs of Bougainville be enhanced to improve farm family livelihoods?</i>

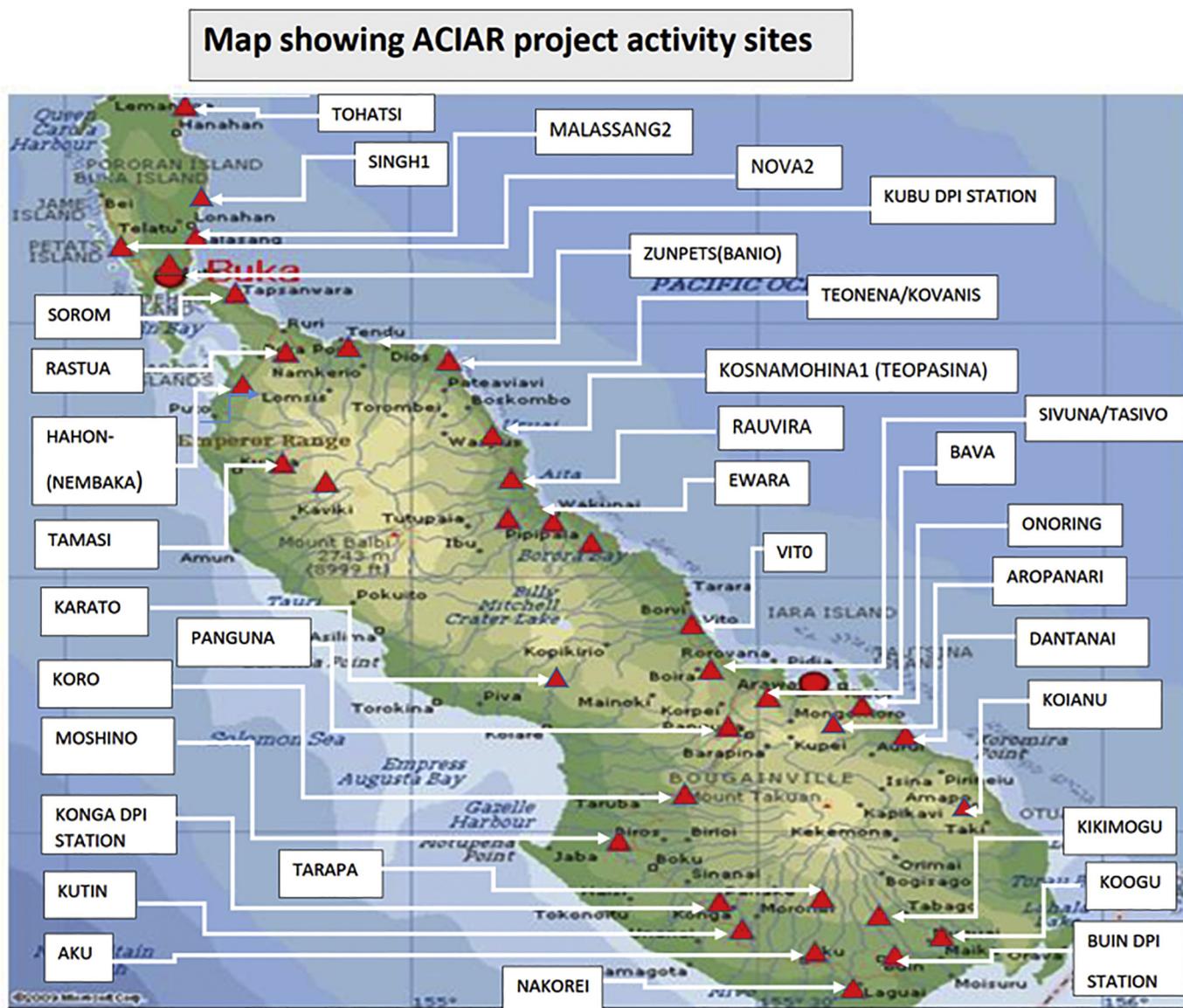


Fig. 1. Map of project activity sites across Bougainville [1].

A total of 2348 households were surveyed. Interviews were conducted within the household, individual interviews were conducted in private, away from other family members.

Data obtained from 5172 individuals (1993 men; 1911 women; 1268 children under 5 years) were analysed including anthropometric data for women and children under five years. The *Report on the Results of a Livelihood Survey of Cocoa Farmers in Bougainville September 2018* was provided to the AROB Government in 2019. The Health Department

used the evidence of significant stunting (low height-for-age) among children under 5 years to prioritise malnutrition in the AROB Strategic Development Plan (1918–22). All regions received a face to face feedback session about the results of the survey. The Livelihood report has also been distributed to the community and is available on a public website managed by the Australian Centre for International Agriculture Research. [38]

The research design, based on the ‘hub & spoke’ model, has three

Box 1

Village Assembly selection principles

- Had to be growing cocoa / or identify as a cocoa farming community
- Motivated and showing leadership
- Possibility for expansion outside of Village Assembly (VA) with large population group
- Need to complement existing projects on the ground
- Balance between villages with good transport access with hard to reach, disadvantaged communities.
- Balance between communities that have and have not received support before
- Avoid duplication with other projects
- Potential for diversification
- Security of farm ownership and Village Resource Centre
- Geographic spread of villages

regional hubs in Buka (north), Arawa (centre) and Buin in the south. Three hub managers (two males and one female) train staff, oversee activities and train and supervise VEWs. The three Hubs are complemented by 11 Village Resource Centres located in targeted Village Assemblies. These centres foster innovation and enterprise development as well implement cocoa, health and education initiatives. They provide a space for community activities in agriculture, health and community development, and a platform for ascertaining community priorities to inform future activities, extending beyond the 6-yr project lifecycle.

The VRCs are managed by VEWs. Intensive training about managing and organizing these centres is provided by the ABG, the PNG Cocoa and Coconut Institute, and PNG University of Natural Resources and Environment and the research team to DPI senior facilitators, District Officers and selected VEWs. Training events usually attract other non-invited participants (male and females) who are permitted to join. VEWs also receive a small gratuity to enable them to create a small business such as a nursery, fermenting and drying station, selling vegetable or cocoa seedlings. Field projects include establishing budwood gardens and nurseries to improve availability of cocoa planting materials and provide an alternative source of income for male and female farmers, especially younger farmers with limited access to land. Different forms of rehabilitating old plantings are being explored to establish the most efficient method. Local soil and/or plant nutrition trials are conducted to improve soil management as farmers have limited access to synthetic fertilisers. Research shows the benefits of on-farm composts that recycle wastes and improve soil fertility to cocoa [29]. Goat breeding and husbandry stations are being established to provide a source of manure for composting, supplementary incomes for women and youth and a source of protein nutrition.

Integrated Pest and Disease Management (IPDM) demonstration plots demonstrate the benefits of improved cocoa management to local farmers. Plots are being located near schools and colleges and cocoa management, food crops, livestock, business and health will be incorporated into curriculums to facilitate skill and knowledge transfer. A group of 13 Department of Primary Industry staff including the regional hub managers attended a 2-week course at the Mars Cocoa Academy in Sulawesi, Indonesia. Mars facilitated the training with follow-up training delivered at the Kairak Training Centre by CCI and UNRE staff. The three hub managers were also introduced to cocoa buyers in Singapore and Malaysia.

Cocoa drying and fermenting equipment are being purchased with guidelines to improve better post-harvest handling, cocoa quality and marketing. Satellite farmer training by VEWs at the VRCs cover topics requested by the farmers including cocoa management and processing, supplementary crops, food crops, livestock, budgeting, market access, family farm team training, water, sanitation and nutrition. The Department of Health is participating in the training. Members of the research team are building capacity through the development of relevant training materials and training health and agricultural staff. The survey results showed most cocoa households have poor nutrition, unsafe water sources and unsafe toilets. A VEW training program on nutrition, water and sanitation including minimising vector borne diseases has been developed to be integrated into training of the VEWs on cocoa management practices.

Increasing demand for 'premium' high quality chocolate driven by consumer awareness for single-origin, organic, ethically traded products provide opportunities for Bougainville to target and supply to this 'niche' market [30]. But inefficient cocoa supply chains mean cocoa farmers cannot effectively or efficiently access these markets. Development across the value chain in Bougainville, including enhancing marketing skills, tracing systems, quality standards, volume and linkages to new buyers is progressing [30]. Marketing activities include marketing training, analysis of export requirements to identify market opportunities, visits to cocoa buyers in Singapore and Malaysia, Australian market analysis and trial shipments and providing market

information in a (local) user friendly manner.

An Annual Bougainville Chocolate Festival (designed in the project) initiated in 2016 by DPI to highlight Bougainville cocoa and to stimulate farmers to improve cocoa quality is now an annual event. Since the inaugural festival the project has equipped a chocolate laboratory and trained staff. Apart from research and training of local chocolate makers the laboratory makes all the chocolate for the Festival competition. The Festival program involves demonstrations and information booths on planting materials, fermentation, livestock husbandry, alternative food crops and public health and nutrition. A number of growers have experienced commercial success from the festivals with buyers from Australia and England actively purchasing the beans from gold and silver medal winners. A validation of the Festival judges' criteria has been in the form of gold medal winners from Bougainville winning prizes at international chocolate competitions in Australia, London, and Singapore. Since marketing training and festivals, cocoa farmers have generated a greater awareness of the global nature of their industry and the need to improve their cocoa farming methods to meet the 'premium market' requirements particularly regarding smoke, free beans, proper fermentation and drying.

7. Intervention strategy phase

This phase describes the activities that are designed to make a change. In One Health research many of the phases are concurrent and keep moving back and forth as mentioned above. Using the survey data about health, we received funding for a vegetable and nutrition sub study in a cross section of villages from the three regions where there was significant levels of stunting (low height-for-age) among children less than 5 years. The study was designed to improve the cultivation of vegetables and nutrition in selected households. Villages received initial training about nutrition as well as how to establish and maintain a vegetable garden. Households are visited every month and mentored and coached by trained staff. Vegetable seedlings are either purchased or being produced by VEWs and made available to the villages participating in the vegetable and nutrition project.

The survey also identified the need to integrate safe water and sanitation into the training program for VEWs as the results showed that 44% of respondents practiced open defaecation. Educating villages about safe toilets includes demonstrating how to keep water sources safe, how to build pit toilets and improve diets for improved nutrition. At the hub level pit toilet construction is planned to be demonstrated alongside agricultural practices, but this is on hold until the COVID-19 pandemic is under control.

Cocoa has the potential to be profitable but shifts in the market require farmers to develop strategies to manage them. Supplementing and diversifying crops and introducing livestock can provide opportunities to earn extra income, engage women and youth and improve access to diverse foods for improved nutrition. While intensification of cocoa production may not be available or accessible to all farmers it can provide new business opportunities such as nurseries, fermentaries, local trading posts that provide fermenting and drying equipment, and small livestock husbandry. These alternative business opportunities are planned for selected VRCs to support engagement of women and youth and generate alternate income sources to build resilience and improve livelihoods and nutrition of the Bougainville farming communities.

8. Systematisation phase

Systems thinking involves solving problems in the context of the wider dynamic system allowing greater precision in understanding how systems work [31]. Systemisation refers to applying the knowledge from the interventions on a wider scale. Knowledge about malnutrition, unsafe water and sanitation are examples described above. Another example is formulation of new policies based on the survey evidence. The hub and spoke model identified the difficulties associated with a

centralized model of service delivery where staff are not familiar with outreach services. Villages have great difficulty in accessing services because of the bad roads and distance from the main service centres. Marketing also suffers through poor connectivity. Mobile support tools are being developed to support VEWs and farmers with information about primary diagnosis of plant pests and diseases.

Perhaps reflecting their experience with previous aid projects, the concept of the VRC (the spoke) was viewed by some village leaders as a constructed building rather than a range of agriculture, health and other social activities. These activities do not need a building to function because trained VEWs can work with the village in the crop, under a tree or in an existing building such as a church hall. This information required additional focus on education about the hub and spoke model as well as discussions with the Ministry of Agriculture and Health about the perceptions of service delivery.

9. Challenges

The challenges faced by Bougainville Cocoa farmers are complex and multi-dimensional, crossing disciplinary boundaries and involving a complex array of relationships – various stakeholders, working across disciplines, different research methodologies and sometimes competing interests. Cultivating and maintaining transdisciplinary collaborations brings with it a number of challenges, which if not carefully considered can cause projects to fall into traditional siloed approaches [32]. A transdisciplinary approach is an iterative process that requires openness, respect and a problem-solving attitude. Time investment is needed, particularly at the start to establish common goals and values. Team members must learn to communicate effectively using a shared language [33,34]. Additional factors which helped facilitate this research include, existing relationships with project partners, regular engagement and communication with stakeholders and time spent working together with farmers in the villages helped to establish common ground, trust and synergies between team members. Project leaders who are able to nurture this kind of collaboration are essential.

Not obvious to the researchers at the beginning of the research was the role that ‘mindset’ played in whether a village could take on board new information and adapt that knowledge to their own situations. Improving livelihoods requires people to change the way they behave in the way they use water, toilet, grow their cocoa, choose what types of food to eat. Asking people to change their behaviour, whether in a high or low resource country is very difficult. With 25 years of stagnating economy and minimal assistance from external sources the capacity of villages, while varied, to adapt to new ideas and practices required careful thought and preparation. Much of the literature on behaviour change focuses on approaches that single-out drivers of change, there is less research available on systems where individuals or groups need to change multiple behaviours [35]. It was therefore important in this circumstance to try to understand the factors that influence behaviours and decision-making within villages and how they interact with the broader social-ecological context [35]. A variety of behaviour change techniques were applied in this approach including, ‘knowledge shaping’, ‘social support’ and ‘feedback and monitoring’ [36]. Building trust and spending maximum time in preparation was central to uptake of an intervention. This was achieved through initial consultation meetings with villages and key stakeholders, before and during the project. Showing, as well as telling, is important. Providing villages with underpinning knowledge along with activities that demonstrated how to put that knowledge into practice was a main first step. The second step was maintaining contact with the village either through coaching and mentoring or through village meetings in the field or in meeting places. Regular contact builds trust as well as influencing peoples’ mindset to move from one of uncertainty and hesitancy to one of innovation and change. Many villages are accustomed to external agencies providing materials and equipment without proper instruction, piloting and training for sustainability. The capacity of a village

and/or readiness for change cannot be gauged by a traditional silo approach whether in health or agriculture [37]. Each alone would not capture the multiple elements that impede or improve farmer livelihoods. Focusing on eradicating cocoa pests and diseases or training farmers how to ferment their beans alone will not improve livelihoods particularly in the context of health and wellbeing of the village, the transport difficulties, lack of education and other factors perhaps unknown to researchers. Attention to environmental factors such as unsafe water sources and lack of safe toilets are just as important as attention to pest and weed management on the farm. The people, the land, the animals, and the crops are all connected and interdependent and must be considered together if livelihoods are to improve.

10. Conclusion

One Health research offers a systematic, logical pathway to assess and identify determinants that leverage health, wellbeing and productivity of humans, plants, animals and the environment in which they inhabit. Investing time at the start of a project is essential to develop strong trusting partnerships. Agreement about communication strategies is key for sustainability and success.

The baseline survey was pivotal to providing the community with evidence showing the multiple factors impacting on cocoa production. It informed the development of extension materials, enterprise development, raising awareness of community health priorities and their impact on cocoa productivity and livelihoods, appropriate health interventions, and an evidence-based cocoa-health Framework (Cocoa Farmers Health Framework that describes best practice in healthcare for villages).

Of the multitude of factors included in the One Health Research Framework (Table 1) only loss of animal habitat and extinction did not emerge as factors. While evidence of extinctions and habitat loss are currently absent in Bougainville there is a lack of data. Mining has had significant detrimental environmental impact in the centre of Bougainville as a result of Panguna mine and its subsequent closing leaving significant land degradation.

The establishment of Regional Hubs and Village Resource Centres provide spaces for a community of learning and practice where information can be shared. Regular stakeholder meetings and chocolate festivals provide further opportunities to disseminate research findings and through a participatory process, continuously develop targeted interventions for improving the livelihoods and health of the community.

Ethics approval and consent to participate

The Research was performed in accordance with the Declaration of Helsinki. The research project was approved by the University of Sydney Ethics Committee (Application Number: 2016/091) and the Autonomous Region of Bougainville Government.

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Authors' contributions

All authors made substantial contributions to the conception and design of the research. MW & JH are joint author leaders of the manuscript. All authors were involved in critically revising the intellectual content of the manuscript. All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Declaration of Competing Interest

All authors declare that they have no conflict of interest.

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