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prepared by	Steven Crimp, Research Fellow, ANU Climate Change Institute
co-authors/ contributors/ collaborators	Dr. Michael Bourke (Tropical Agricultural Consultants), Dr. Lilly Lim-Camacho (CSIRO), Mr Tom Sloan (Sustineo), Mr Federico Davila (Sustineo), Ms. Nici Sweaney (Sustineo), Dr. Birte Komolong (NARI), Mr Johannes Pakabul (NARI), Ms. Julie Sip (NARI), Dr. Philip Kokic (PNK Consulting), Mr Jeffery Yapo (NARI), Mr Tai Kui, Mr Kasis Inape (PNG NWS), Ms. Nanao Bouauka Vulum (PNG NWS), Dr Andrew Rose (Anglo Pacific Research), Dr Brendan Jinks (ANU)
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Contents

1 List of acronyms

Acronym	Definition
ACGCM	Atmosphere-ocean Coupled Global Circulation Model
ACIAR	Australian Centre for International Agricultural Research
APEC	Asia-Pacific Economic Cooperation
APCC	APEC Climate Centre
APSIM	Agricultural Production Simulator
BIC	Bayesian Information Criteria
CCAFS	Climate Change Agriculture and Food Security
CLIK 1.0	APCC Climate Information Tool Kit
COLA	Center for Ocean-Land and Atmosphere
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ECCC	Environment and Climate Change Canada
ECMWF	European Centre for Medium range Weather Forecasting
ENSO	El Niño Southern Oscillation
EUROSIP	multi-model system from ECMWF
GAM	Generalized Additive Model
GFDL	Geophysical Fluid Dynamics Laboratory
JMA	Japanese Meteorological Agency
MME	Multi-model Ensemble
N	Nitrogen
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NMME	North American MME
NOAA	National Oceanographic and Atmospheric Administration

Acronym	Definition
OCCD	Office of Climate Change and Development (PNG)
POAMA	Predictive Ocean Atmosphere Model for Australia
RUE	Radiation Use Efficiency
SCF	Seasonal Climate Forecast
SCOPIC	Seasonal Climate Outlooks in Pacific Island Countries
SPC	Secretariat of the Pacific Community
USP	University of the South Pacific

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Photo: *Students from the Ontobura Primary School, standing near the location of the weather station*.

3 Executive summary

Within the broader development goal of sustaining and, where possible, improving the food security of Pacific islander smallholders and their communities, the primary aim of this project is to improve PNG highlands food security in the face of climate variability and change through specific focus on staple food production systems**.** A secondary aim of this project is to support the enhancement of existing agricultural production through the provision of seasonal climate information relevant to respond to unfolding seasonal environmental conditions.

The SRA project strategy involves using social network analysis surveys, expert knowledge, spatial mapping and statistical analysis as ways to identify how climate information is, and could be, disseminated effectively amongst rural communities and government agencies; the form the seasonal climate information would need to take in order to be effectively understood and actioned as well as the possible farming options to pursue during different season types.

The SRA has seven clear objectives. These are:

1. Building capability of PNG research agencies and rural communities to link to regional climate forecasting capability through examination and characterisation of formal and informal knowledge networks.
2. Based on the knowledge network analysis, identify new operational seasonal climate forecast knowledge products from around the world, that would have relevance to PNG in helping communities and agencies, and examine how these could be hosted by the PNG weather service to provide information relevant to agriculture.
3. For three case study sites, establish weather stations to monitor temperature, rainfall and solar radiation and work with PNG Weather Services, NARI and community leaders to effectively manage and disseminate the climate information in formats usable by the community. These will become part of the PNG Weather Services NWS weather station network in order to improve the observation of weather and climate trends in the Eastern Highlands.
4. Understanding how agricultural vulnerability has changed by examining and mapping changes in historical rainfall and temperature.
5. Developing climate smart response options for farming communities in the face of below “normal” (e.g. El Niño) and above “normal” (e.g. La Niña) seasonal rainfall conditions, based on expert knowledge, previous research activities and traditional ecological knowledge (e.g. Bena coping strategies).
6. Determination of information/technology/asset gaps in the dominant farming systems of the case study districts and present a gap analysis to ACIAR and NARI.
7. Drafting a set of recommendations on research for development questions/topics relevant for climate smart agriculture in PNG.

The social network analysis revealed some very important insights into how seasonal climate information should be effectively communicated with PNG communities. The overall network behaviour showed that church, community, and family were the most trusted and most central groups in across all villages. These three groups also created cliques (sub-networks), meaning that they interact with each other frequently. Government was a highly trusted source reaching the central groups, however they were only disseminators of knowledge, not recipients. This raises questions regarding the extent to which government is able to access and receive feedback from the communities and adjust their information dissemination strategies.

Farmer-centric analysis shows that farmers are highly trusting of most major groups: community, church, and family. Farmers also showed high levels of trust in NARI extension officers. Overall, farmers were the recipients rather than disseminators of knowledge. This provides a range of opportunities to reach farmers via different major groups in the community. Care needs to be taken to reduce the chances of farmers receiving conflicting SCF information from different sources, as they might not know who to trust if information is not consistent.

There are strong sub-group connections between church, community, family, and Wantok[1]. This means that these cliques and strong connections can act as catalysts of information dissemination. They can be targeted to disseminate information to smaller, more distant groups, such as youth groups and women's groups.

Drought early warning systems were consistently identified as the most important SCF information needed. Rainfall and temperature forecasts were the next most important types of information. Similar to the trust maps, the overall network shows that family, community, and church groups were the most important sources for obtaining different SCF information. Farmers are not perceived as important for disseminating SCF, confirming that they are passive knowledge recipients in these networks. Some differences between villages were noted. For example, Okapa reflects the common finding that family, community, and church are highly influential and exchange different types of knowledge. Outlier groups are farmer organisations, natural sources (learning from observation) and agricultural extension officers. However, the findings for Ontobura were contrasting. Family, community, and church are perceived as most useful sources only for weekly temperature, drought early warning information, and rainfall (daily and seasonal forecast). Different types of information (daily temperature, monthly and weekly rainfall) seems to be best sourced from government agencies, media, farmer organisations, and agriculture extension officers.

There were no major differences between males and females regarding overall trust. Both sexes (or women and men) were found to be highly trusting of the central groups of church, family, and community. Males placed farmers and NARI as central sources of obtaining SCF information, whereas females saw family and community as more central information sources. The survey as a method is unable to determine how men and women use SCF to inform farming practices. Qualitative methods can fill this gap.

The findings above show some major themes important for future surveys and disseminating SCF to end users. Across the different maps, it is evident that the community/church/family/Wantok individual groups and cliques are important sources of information, and are highly trusted. All groups were consistently central in all maps, and acted as avenues to reach smaller community groups, such as farmers or women's groups. These findings indicate to the importance of acknowledging the role of social structures in disseminating technical information – something that is often overlooked in technology transfer initiatives. This overall behaviour across all villages provides an overview of possible groups to target for SCF information. If the project is to have sustained uptake of SCF, then future surveys will need to look at ranking how SCF is used by the different groups. This would enable the research team to link the SCF to farming practices.

Drought early warning systems, temperature, and rain forecasts were the most important types of information. Multiple sources were seen as important for disseminating information. This provides a broad opportunity for future SCF dissemination strategies that target core trusted groups (family, community, church) and enable them to reach other groups.

There needs to be important consideration into the impact pathway for ensuring sustained adoption of SCF knowledge products. The survey revealed that farmers are passive recipients of information. Literature shows that for SCF to have impact it needs to be relevant to the end users and has to be consistently presented in an appropriate format. Quantitative surveys are unable to show how information is used to inform different farming practices across different commodities. Embedding a series of monitoring and qualitative research components to future SCF projects would allow research teams to understand how technical outputs can be used by farmers to adapt to climate change.

The design, conduct, and findings from this SNA present lessons for up-scaling to other countries. These lessons covering training, conduct, and broader SCF research recommendations are provided below.

Training lessons: use the lessons identified in the Training Report to improve training design, translation, delivery, and contingency plans. See Appendix A for the overview of these training lessons.

[1] Wantok grouping refers to people from a particular clan or tribe, and thus represents more than a specific sub-group such as family or community

Survey conduct lessons:

- Work with key 'champions' in partner agencies in country who demonstrate leadership and can influence others attending training or conducting the survey.
- Move away from paper based surveys towards tablet computer based surveys. This reduces the risk significant delays, as the tablet software can be designed so that data 'errors' are minimised. Data output is also more likely to be consistent. The use of tablets can provide a template for 'rapid' network assessments, so that knowledge based research outputs in can target the most relevant groups.
- The questions need to have more clarity of what community means. This survey showed that there are multiple groups within 'community', which only at an aggregate level present meaningful SNA data.
- Target end-users of SCF information to identify what their needs and understandings of SCF area, and their role in the social network.
- Design questions on **how information is used, especially by different sexes** Such questions can provide more ways of looking at whether men and women use information differently. If it is found that there are differences, there could be important findings for how SCF is targeted and disseminated.
- Allow for a major qualitative component that explores why the network behaves the way it does, and why SCF information is needed and how it is used. SNAs present a 'snapshot' of a network, but not the reasons behind it. Qualitative data can reveal how SCF information is expected to be used by different groups, and can help inform the design of dissemination strategies. Qualitative research can also help guide gender analysis and identify differences that may exist.

Broader SCF research and design of impact:

- Design an impact pathway of how technical SCF information will reach end-users, and how this information can be adopted long term.
- Capture as many baselines on commodity production economics, natural resource issues, and the knowledge system of target villages when projects begin. Baselines will allow team monitor evaluate and learn as research findings emerge and are adopted by end users.
- Aim to understand if there is conflicting information on SCF for food production being delivered by end-users (farmers).
- Work with key 'boundary and knowledge brokering' cliques that are highly trusted in the villages to disseminate information. This can enhance legitimacy of knowledge products.

In terms of the placement of the weather stations and development of software to analyse the data from the stations, the weather stations were installed but have only been collecting data for a period of five months. Unfortunately the dataset was too short to test the analysis software and so long-term records from Aiyura were used to test the utility of the software. The analysis software was able to quickly analyse the trends for 57 different derived temperature and rainfall variables and highlight those that were statistically significant. Future version of this software will include an automated approach to graphing these trends.

In terms of the spatial mapping of rainfall and temperature trends for the whole of PNG, the statistical approach developed allowed the extrapolation of sparse spatial and temporal records to produce the maps. The results from this analysis show considerably warmer conditions over the western half of the country and drier conditions in the south west and wetter conditions over much of the rest of the country. This mapping does highlight regions where the rate of climate change is happening more rapidly than others but also shows where seasonal variation has increased.

The review of resilient farming systems served to identify a series of possible farming options to cope with both extreme dry and extreme wet conditions. These adaptation options will be tested during the next phase of this project.

The scoping study has served to identify a number of gaps and strengths of existing institutions in the delivery of seasonal climate information and the sections that follows presents a series of recommendations that serve to improve capacity and service the community with regard to seasonal climate information.

4 Background

The IPCC 5th assessment report identifies small island states as being the most vulnerable countries of the world to the adverse impacts of climate change (IPCC, 2014). In an earlier report produced by the World Bank it was identified that "*climate change holds the potential to radically alter agroecosystems of the Pacific in the coming decades and there is already evidence of devastating crop failures in some island countries. Over the long term, adapting and mitigating impacts from climate change will have to be a top priority for all countries in the region*" (World Bank, 2011).

Communities reliant on agriculture-based livelihood systems have been identified as particularly at risk from climate change, due to likely increases in crop failure, new patterns of pests and diseases, lack of appropriate seed and plant material, and loss of livestock (Taylor et al., 2016). In the Pacific region, recent shortfalls in agricultural production resulting from changing export markets, commodity prices, climatic variation, population growth and urbanisation, have meant a greater reliance on imported foods, thus contributing further to regional food insecurity concerns for the future (Taylor et al., 2016).

A number of activities are already underway in the Pacific region to identify ways to ameliorate existing climate risk and enhance current agricultural production. Whilst these activities are important to ensure long-term agricultural sustainability, there remains a significant degree of uncertainty as to how effective activities may be with an increasingly variable future climate.

Accordingly, this SRA has examined ways to improve PNG highlands food security, in the face of climate variability and change, through specific focus on staple food production systems. A secondary aim of this project is to support the enhancement of existing agricultural production through the provision of seasonal climate information relevant to respond to unfolding seasonal environmental conditions.

The Government of Papua New Guinea (PNG), led by the Climate Change Development Authority (CCDA), has identified nine priority areas for adapting to future climate change. Food security is one of these priority areas. However, due to a limited amount of accessible climate-related data, it is difficult to know how climate change will influence these sectors, where impacts will be most acutely felt, and identity appropriate solutions. This report addresses these issues for food security in PNG.

4.1.1 Food supply in PNG

Main sources of food

The main sources of food in rural PNG are locally grown staple foods, such as sweet potato, taro, banana, yam, cassava and sago; and other garden foods, including sugar cane, coconut, numerous vegetables and various fruits and nuts. Also eaten is imported rice; foods manufactured from imported wheat, such as bread, biscuits and noodles; meat and fish, both local and imported; and minor foods including refined sugar, animal fat, vegetable oil, dairy products and eggs. About three-quarters of food energy is derived from the garden foods, while imported rice and wheat-based foods contribute a further 14% (Table 1). The contribution of meat and fish to food energy is low, although meat and fish provide one-quarter of food protein.

Among the locally grown staple food crops, sweet potato is by far the most important, accounting for two-thirds of locally grown staples. This is followed by taro, banana, cassava, yam and coconut (Table 1).

Import dependency

It was estimated in 2006 that 83% of food energy is derived from foods produced in PNG, and 17% from imported items. Corresponding figures for food protein are 76% and 24%. A study of consumption ten years earlier in 1996 gave similar results. In the earlier study, it was found that locally grown food provided 80% of food energy consumed in PNG. In 1996, rural villagers obtained 85% of their food energy from locally grown food and urban people obtained 50% (Gibson 2001c). Hence the level of food import dependency is not high for most of the population. It is much higher for the one-fifth of the population who are based in urban centres and in rural non-village situations. There, people obtain about half their food energy needs from imported foods.

The two most important imported food items are rice and wheat (Table 1). Consumption of rice increased greatly in 1972, 1997-98 and 2015-16 when there were widespread subsistence food shortages caused by drought and frost. It also increased in 1985–87, with the most likely explanation being increased spending on imported food during a period of exceptionally high coffee prices.

Table 1: Estimated food consumption in PNG by food type, 2016

Food	**Estimated quantity**	
	tonnes/year	**kg/person/year**
Staple foods (PNG grown)		
Sweet potato[a]	3,470,000	416
Banana	703,000	84
Yam (all species)	440,000	53
Cassava	438,000	52
Taro	377,000	45
Chinese taro	364,000	44
Sago	134,000	16
Irish potato	30,000	4
Rice (PNG grown)	1,000	0.2
Other garden foods (PNG grown)		
Vegetables	683,000	81
Sugar cane	508,000	61
Coconut	164,000	20
Fruit	137,000	16
Peanuts and other nuts	27,000	3
Imported energy food		
Rice	251,000	30
Flour	146,000	18
Meat		
Pork (local)	40,000	5
Chicken (local)	35,000	4
Sheep meat (imported)	33,000	4
Bush meat (local)	28,000	3
Beef (local and imported)	10,000	1
Tinned meat and offal (imported)	5,000	0.6
Fish and other seafood		
Fresh and smoked (local)	68,000	8
Industrial tuna (local)	20,000	2
Other fish (imported)	15,000	2
Other food		
Sugar (local and imported)	46,000	6
Animal fat (imported)	8,000	1
Fruit and vegetables (imported)	8,000	1
Vegetable oils (mostly imported)	8,000	1
Milk and other dairy products (imported)	7,000	1
Eggs (local)	4,000	0.5

a Estimated sweet potato consumption excludes that fed to pigs in the highlands.

Source: Estimates based on those in Bourke et al. (2009: Table A2.1.1); updated for population growth between 2006 and 2016; no adjustment for minor changes in composition over past decade; estimates rounded to 1000 tonnes

Devaluation of the PNG kina against the United States dollar from 1994 onwards resulted in rapid increases in prices of imported items, including foods. This was particularly marked from 1998 onwards and resulted in reduced rice consumption per person after 1998.

Number of people eating each major staple food

Estimates of the number of rural villagers who grow and eat each of the major and minor staple foods is given in Table 2. The dominance of sweet potato is clear: two-thirds of the population grow sweet potato as their 'most important food' and 99% of the population grow some sweet potato. Banana is very widely grown — 96% of rural villagers grow it — but banana is the most important food for less than 10% of the rural population. A similar situation applies to *Colocasia* taro (Asia–Pacific taro), which is grown by 95% of the rural population, but is now the most important food for only 6% of rural villagers.

Significance of domestically traded food

Significant volumes and values of fresh food are grown for sale in PNG. Analysis of data recorded in the early to mid-1990s in the Mapping Agricultural Systems of PNG database indicates that domestically marketed food is second only to Arabica coffee in terms of cash income from agricultural activities for rural villagers. These data also show that sale of fresh food involves more rural villagers than any other agricultural activity.

However, staple energy foods constitute only a small proportion of fresh food sold in markets. Vegetables, fruit, nuts and other foods are generally much more important. There are no reliable estimates of the value or volume of the staple foods sold in all PNG markets. While the volume and value of marketed staple foods are significant, the marketed portion is probably less than 1% of total production for the most important staple foods of sweet potato, taro, banana, sago and yam.

Table 2 Estimated rural population growing staple food crops in 2016

Crop	Most important food		An important food		Grown for food	
	Population	%	Population	%	Population	%
Sweet potato	4,456,008	66	1,014,066	15	6,628,051	98
Banana	617,197	9	2,147,075	32	6,456,613	96
Taro (*Colocasia*)	424,150	6	1,641,874	25	6,386,355	95
Greater yam (*Dioscorea alata*)	–	–	267,395	4	4,013,277	60
Cassava	68,555	1	824,224	12	3,709,645	55
Chinese taro (*Xanthosoma*)	206,498	3	1,247,653	19	3,590,677	54
Coconut	2,659	<1	2,381,698	36	2,456,106	37
Sago	735,730	11	233,125	3	2,195,206	33
Lesser yam (*D. esculenta*)	435,149	6	379,349	6	2,191,934	33
Irish potato	–	–	193,410	3	1,070,030	16
Taro (*Alocasia*)	–	–	–	–	504,246	8
Queensland arrowroot	–	–	–	–	294,934	4
Taro (*Amorphophallus*)	–	–	–	–	223,531	3
Swamp taro (*Cyrtosperma*)	1,088	<1	5,546	<1	50,557	<1
Aerial yam (*D. bulbifera*)	–	–	–	–	34,461	<1
Yam (*D. nummularia*)	–	–	–	–	11,826	<1
Yam (*D. pentaphylla*)	–	–	–	–	5,498	<1

Percentages are the proportion of the estimated total rural village population (6,732,700) in 2016 who grow each crop in each class. Column totals add up to more than 100% because people are counted more than once where they grow more than one crop in that class.

Source: Mapping Agricultural Systems of PNG database; Bourke and Allen (2009: Table 3.1.1); updated for population growth between 2000 and 2016

4.1.2 State of food availability

Generally, carbohydrate or staple foods are readily available for most of the rural population. In some locations, carbohydrate foods are chronically scarce. These include a limited number of locations in the central highlands.

While carbohydrate food is generally abundant, the same is not always true for high protein and energy-dense foods, such as vegetable oil or animal fat. In the central highlands, abundant sweet potato is fed to pigs, which provide these two food groups to some degree. In locations between the central highlands and the coast, that is, the lowland plains and in the intermediate altitude zone, people are particularly short of both protein and energy-dense foods.

Imported processed food is generally readily available, except in extremely remote locations. The factor limiting consumption of processed foods, including rice, wheat-based foods, tinned meat and tinned fish, is primarily available cash followed by preference.

4.1.3 Stability of food supply

Overall, the supply of locally grown food is reasonably stable in PNG. Production from subsistence food gardens varies over time, as a result of variation in the planting rate, influence of rainfall and temperature on crop yield, and interruptions caused by local factors, such as inter-clan violence in the highlands. In the past, people planted a greater area of food garden than was needed for subsistence purposes so as to reduce the impact of these fluctuations. In the modern context, access to cash acts as a very important buffer for subsistence food producers. When subsistence food is scarce, people who have some cash are able to buy locally grown or processed food, with imported rice being the most important food reserve. However, many people do not have savings or the ability to generate cash at short notice and they are unable to purchase food to supplement subsistence production.

Extreme climatic events result in widespread and major food shortages. The most recent widespread shortages were caused by major droughts and associated frosts at high-altitude locations (above 2200 m) in 1997 and in 2015.

4.1.4 Changes in food consumption over time

Food consumption in PNG has changed significantly over the past 300 years, and particularly over the past 50 years. The major changes include the adoption of sweet potato in both the highlands and lowland regions of PNG.

Sweet potato was introduced and widely adopted into highland agricultural systems about 300 years ago (Ballard 2005, Bayliss-Smith et al. 2005, Wiessner 2005). This new food from South America displaced taro as the major staple food in the central highlands. By the early 1920s the staple food for almost all highlanders east of the Strickland River was sweet potato (with the exception of the area near the Lamari River south of Kainantu).

Cassava and maize have been adopted in some locations, particularly below 1500 m altitude over the past 50 years. However, sweet potato remains by far the most important food crop in the highlands and dominates land use and food consumption.

By 2014, sweet potato was the most important food, supplemented by cassava, with taro and Chinese taro only very minor foods (surveys conducted by the Michael Bourke in 1979, 1992 and 2014). Following the drought in 2015 some resurgence in in cassava production has occurred, with a consequent decline in relative importance of taro, yam and sago.

Imported food

Consumption of imported foods or those made from imported foods — in particular, rice, wheat-based foods, animal fat, vegetable oil, tinned meat and tinned fish — has increased rapidly over the past 50 years as people have entered the cash economy, particularly through sale of food and export crops. Consumption of rice and wheat has reached a plateau in recent years. Consumption of imported meat and fish decreased greatly after the kina was devalued in the late 1990s (Bourkle *et al*., 2016).

Domestically marketed food

Sales of locally grown foods have increased steadily and both rural villagers and urban people buy fresh food in fresh food markets. Production and sale of fresh food on the domestic market received a boost after the devaluation of the kina in the late 1990s (Bourke *et al.,* 2016).

4.1.5 Climate sensitivity of PNG food production

Around 80% of food consumed in PNG is grown in situ. Historical analyses have shown that the variability of food production is strongly correlated with climate variability. A strong El Niño event reduces rainfall significantly in normally wet areas for some months and prolongs dry seasons. This is because PNG's characteristically high rainfall is the product of moist tropical air masses intersecting with atmospheric instability, resulting in large annual rainfall amounts. During a strong El Niño event, the western Pacific cools and the Walker circulation reverses so that the atmosphere becomes more stable and air masses are lower in moisture content. The result is less than below average rainfall for extended periods, prolonged drought conditions and significantly less cloud cover. At altitudes above 2,200m the lack of cloud cover at night encourages radiative cooling and temperatures can fall to below zero resulting in frost and damage to crops.

Historical records reveal there have been 11 droughts associated with El Niño events in PNG between 1896 and 1997, but severe disruptions to food and water were reported only in 1902, 1914, 1941, 1997 and 2015. The 1997 and 2015 events are probably the most severe since 1914. At altitudes above 1700m, repeated frosts killed all sweet potato, the staple food for this region. At lower altitudes, newly planted gardens failed because of a lack of rain and because streams used to produce sago dried up. Taro growers were forced to remove plants from gardens and place them near large streams to maintain planting stock. Wildfires destroyed villages and killed people and pigs. Large areas of montane forest trees killed by fire in 1997 are still evident on highlands mountain ranges today. Forest fires disrupted long fallow shifting cultivation systems between the Fly River and the Sepik River (D. Jorgensen, pers. comm.) where rainfall averages as much as 8,000 mm per year. The Fly River became too shallow for shipping and Rouna hydro-power station was closed to preserve Port Moresby's water supply.

By December 1997, national surveys of food and water found that over 260,000 people were eating 'famine' foods such as wild yams, tree leaves and banana roots. A further 980,000 were eating small amounts of poor quality garden food. Rural people survived by employing a number of strategies: eating 'famine' food; purchasing imported food with cash raised by selling off pigs or from savings; moving to places where food was available; moving to towns to stay with relatives who had wage-paying employment; and receiving rice, flour or cash from relatives in employment (Allen 2015). Australia used ADF aircraft to reach 100,000 people without food, living in places only accessible by air. But, as a result, the numerous company and mission light aircraft that regularly flew to the same airstrips used by the ADF were grounded and a number were taken to Indonesian Papua to provide relief transport there (Allen 2015).

In 2015 the first signs of the impact of the impacts of the El Niño were press reports of frosts. Social media postings preceded press reports, contain photographs of frosted gardens at Tambul and Kandep. Mobile phones are now widespread in rural areas. The National Agriculture Research Institute's (NARI) Tambul station reported frosts on the nights of 19 and 26 July and 10, 11, 12, 13 and 14 August, a very similar pattern to 1997. In 1997 frosts continued into September and early October (Allen 2015).

The 2015 frosts had an immediate impact on sweet potato and potato crops, with an estimated 85% loss of production. The protracted nature of the frosts also meant that food shortages were immediate as well as a six month lag before sweet potato was available once more. During that period infant mortality rates increased and communities moved down to the lower altitude regions. In 1997 and 2015 the move to the lower altitude areas was not a successful adaptation option as the drought conditions were widespread and severely reduced sweet potato production in the lower valleys to the extent that the additional communities could not be sustained. Individuals with relatives in towns who were earning cash, relied on “Wontok” related cash and food sent by urban relatives.

In August 2015, low water levels in mainly Highlands rivers, as well as the Fly and Sepik rivers, resulted in the closure of operations at the Ok Tedi mine, a decision that was also related to low copper prices and a mine collapse.

4.1.6 Climate risk services in PNG

The PNG Government has developed a number of programs and projects to improve and/or enhance resilience to climate variability and change. Most recently the Papua New Guinea (PNG) Strategic Program for Climate Resilience (SPCR) has been established to enhance PNG‘s resilience to climate change through improved access to resources, knowledge, and tools and climate resilient infrastructure at the national, sectoral, district, and community levels. To date much of this funding has been directed to developing climate resilient infrastructure and not at the enhancement of early warning systems and agricultural seasonal forecast capabilities.

In the near future the Climate Risk and Early Warning Systems (CREWS) initiative will begin to consider investment in PNG. This initiative aims to mobilize more than US$100 million by 2020 to strengthen risk information and early warning systems in least developed countries and small-island developing states. Some investments have already been made in the Pacific, but investment in PNG may be 1 to 3 years away.

On 13 October 2016, six national institutions that have key roles in early warning in Papua New Guinea, signed a Memorandum of Agreement to collaborate on the establishment, capacity building, and sustainable operation of a National Multi-Hazard Early Warning System. These institutions include the Department of Mineral Policy and Geohazards Management, National Weather Service, Conservation Environment Protection Authority, Department of Agriculture and Livestock, Climate Change and Development Authority, and National Disaster Centre. This agreement was established to address the Regional Integrated Multi-Hazard Early Warning System (RIMES) initiative. Further efforts are required to establish operational services.

The UNDP has provided support and services on climate change to the Government of PNG through the Office of Climate Change and Development. This helped the Office of Climate Change and Development mobilise US$6.3 million from Adaptation Funding to implement pilot integration of climate change adaptation and disaster risk reduction through policy formulation, preparedness, response plans and strategies to enhance the capacity of agencies and officials of the public and private sector, civil society organizations and vulnerable communities of the North Coast and Island Region of PNG.

Discussion of climate risk services for PNG agriculture requires an assessment of 1998 budget papers. In these papers is was confirmed that an allocation of K25m for drought relief, K38m for additional education subsidies (aimed to lessen the impacts of the drought on local cash flows) and K8m for medical supplies were made. Donor expenditure on drought preparedness is unclear – an estimate of AU$30m for drought relief was made in 1990 by Australia. Other donors provided support but it is not possible to quantify this with any accuracy.

To estimate the amount required to deal with drought preparedness today we need to extrapolate this figure. Given inflation from 1997 to 2016 of 240% (using CPI indexes from the IMF), a population increase is some areas of 50%, and an AU$ to Kina exchange rate of around 2 to 1, the total budget requirement to address a drought event today would be approximately K668m ((K25m+K38m+K8m+K60m (donors)) x 3.4 (inflation) x 1.5 (population)). This estimation clearly suggests the 2016 allocation of K30m is inadequate. Whilst a considerable amount has been invested in drought preparedness some commentary suggests that this has done little to alleviate the vulnerability of rural communities.

Photo: *Local planting of sweet potato Central Highlands*.

5 Objectives

Within the broader development goal of sustaining and, where possible, improving the food security of Pacific islander smallholders and their communities, the primary aim of this project is to improve PNG highlands food security in the face of climate variability and change through specific focus on staple food production systems. A secondary aim of this project is to support the enhancement of existing agricultural production through the provision of seasonal climate information relevant to respond to unfolding seasonal environmental conditions. This understanding and the tools developed to analyse these impacts will be available to a range of users including research and agricultural extension staff. To this end, the project has seven broad objectives. These are:

Objective 1: Building capability of PNG research agencies and rural communities to link to extreme event warnings and regional climate forecasting capability - involving the establishment of a social network analysis extending across the Eastern Highlands province. This survey will determine how information relating to weather extremes and seasonal climate conditions is disseminated across formal networks e.g. agricultural extension groups and informal networks e.g. rural communities. This analysis will identify where this information is effectively and ineffectively disseminated what sorts of climate information is most and least effectively communicated. The SNA will also allow the mapping of individuals and organisations that are information facilitators, gate keepers or major communication hubs. This will assist in the improved communication of new climate related information in the future.

- Activity1.1: Identify case study locations in the Eastern Highlands Province to undertake the social network analysis (SNA).
- Activity 1.2: Identify "Tok Pisin" speakers who would be able to undertake the SNA in each location. Develop a draft design of the SNA and test this with on-ground partners.
- Activity 1.3: Undertake a training session with our on-ground partners in both undertaking the SNA and collating the data.
- Activity 1.4: Complete the analysis of the SNA data and produce the network information.

Objective 2: Identify new seasonal climate forecast knowledge products to help communities and agencies respond to specific climatic challenges - through review and inventory of available operational forecast information for PNG and comparison against the SNA analysis undertaken in objective 1, this activity will identify possible early warning and new seasonal climate forecast knowledge products that could be developed and disseminated. This objective will include a series of facilitated workshops to determine how the operational climate information could be incorporated in agricultural practises and food security decisions to make them more climatically resilient.

- Activity 2.1: Undertake a review of existing operational seasonal forecasts and derivative information that would potentially be available and usable in PNG.
- Activity 2.2: Catalogue useful knowledge products and compare these products with the results from the SNA regarding dissemination modes.
- Activity 2.3: Develop a set of notional SCF knowledge products and test the utility of these within the case study communities identified in activity 1.1. Finalise SCF knowledge products based on feedback.

Objective 3: Establish three new weather stations in collaboration between NARI and NWS - through collaboration with the NWS three new weather stations (with soil moisture measuring capabilities) will be established in the Eastern Highlands province. The establishment, maintenance and data extraction will be managed collaboratively between NARI and NWS staff and involve representatives from leading community groups. Data extraction and processing into information directly relevant for agronomic decisions e.g. starting soil moisture, rainfall deficit etc., will be automated and presented to each of the communities where the weather stations reside.

- Activity 3.1: Purchase and transport three automated weather stations to the case study locations.
- Activity 3.2: With NARI and NWS locate and establish the weather stations in each community.
- Activity 3.3: NWS to train staff from NARI and selected community representative to maintain the weather stations and download the climate data.
- Activity 3.4: CSIRO and NWS staff to develop automated software to develop agriculture specific information products.
- Activity 3.5: Software tested on weather station data.

Objective 4: Understanding how agricultural vulnerability has changed by examining and mapping changes in historical rainfall and temperature variability – using a combination of point based data from the 39 weather stations in PNG and gridded climate information from the National Centers for Environmental Prediction (NCEP) this activity will show how climatic conditions have changed across PNG. This information will include the production of variables directly relevant for agriculture i.e. changes in growing degree days, drought frequency and duration, heat stress and water deficit (cumulative rainfall minus cumulative evaporation). These maps will highlight regions where historical changes have been large and will provide important information regarding changes in food production conditions.

- Activity 4.1: Download data from the existing 39 weather stations in PNG. Undertake quality control and error checking on sites with sufficient record length.
- Activity 4.2: Download relevant NCEP gridded data and statistically enhance the resolution using quality controlled weather station data.
- Activity 4.3: Develop a list of climate indices relevant for PNG agriculture based on local expert opinion.
- Activity 4.4: Compare the change in frequency of these climate indices for two discreet periods i.e. 1960 to 1984 and 1985 to 2015.
- Activity 4.5: Produce a series of anomaly spatial maps that plot the difference in the climate indices across the two periods.

Objective 5: Developing climate smart response options for farming communities – based on expert knowledge from existing research activities, published literature, as well as traditional ecological knowledge, the project team will undertake the development of a set of farming options for case studies in the Eastern Highlands Province that will be effective in mitigating potential losses during below “normal” (e.g. El Niño) and above “normal” (e.g. La Niña) seasonal rainfall conditions as well as help to mitigate heightened frost risk during strong El Niño years. These options would represent no regrets management adaptations to drought and very wet climate conditions.

- Activity 5.1: Review existing literature sources as well as conduct targeted community based interviews to develop a set of “no regrets” farming options for case study sites in the Eastern highlands province that will be effective in mitigating potential losses during below “normal” (e.g. El Niño) and above “normal” (e.g. La Niña) seasonal rainfall conditions.

Objective 6: Determination of information/technology/asset gaps and strengths in the dominant farming systems of the case study districts – using a range of expert knowledge sources, information from the SNA survey and workshop activities the project team would identify information, technology and asset/infrastructure gaps and strengths currently restricting agricultural productivity gains and food security outcomes. This gap analysis will present a set of possible priorities for AR4D action.

- Activity 6.1: Undertake “Gaps and Strengths” analysis based on expert knowledge sources, information from the SNA survey and workshop activities.

Objective 7: Drafting a set of recommendations on research for development questions relevant for climate smart agriculture in PNG – using a range of expert knowledge sources, information from the SNA survey and workshop activities the project team will identify a series of recommendations regarding R4D activities that would serve to improve agricultural productivity and food security in response to climate variability, as well as the information required to develop climate smart agriculture in PNG.

- Activity 7.1: Undertake informal interviews with experts and key institutional staff to identify a set of recommendations on research for development questions relevant for climate smart agriculture in PNG.

Photo: *A field assessment of sweet potato*.

6 Methodology

An overview of the activities discussed in Section 5, their sequencing and relation to the seven objectives are provided below.

Objective 1: Building capability of PNG research agencies and rural communities to link to extreme event warnings and regional climate forecasting capability.

The three case study locations were selected in consultation with staff from the National Agricultural Research Institution. The three cases study sites were selected based on their proximity to the NARI regional office in Aiyura and to passable roads as well as existing extension activities and community interest.

Human Research Ethics approval was sought via CSIRO to undertake the survey with the three community groups and was granted in March 2017. A draft of the survey was established by CSIRO staff and shared with Sustineo staff for review. A revised version of the survey was then shared with NARI staff and Anglo Pacific Research (APR) for further review. Once a consensus version of the survey was established, Anglo Pacific Research then undertook the translation of the survey into “Pisin”.

Initially, the survey training was intended to be conducted solely by Sustineo with up to 10 NARI staff. The NARI team would then implement the survey without further directly involvement from Sustineo or CSIRO. Based on discussions with CSIRO, it was agreed that benefits would emerge from engaging a local social research firm APR as part of the training and data collection. These benefits included additional capacity building, ensuring the required number of surveys could be collected, and increased confidence in data quality.

The ‘hybrid’ model proposed would have involved the co-facilitation of training by Sustineo and APR, and included both APR enumerators and NARI staff. During the conduct of fieldwork, the NARI staff would be embedded within the APR team. This would have aimed at providing strong capacity building opportunities for NARI staff, with lessons from training being reiterated in the field. It would also have provided a clear line of sight for quality control within the enumeration group.

The finalised plan was for training to be conducted with at least 6 NARI staff, for training activities to be conducted in two half-day periods, and a pilot to be conducted around the installation of the weather stations.

There were a number of factors that influenced the conduct of training and resulted in adaptations to the original training plan. Visa issues resulted in the delay of training however APR staff had already mobilised when notified and, as a result, undertook their data collection as planned. This resulted in a revision to the hybrid approach to training and data collection, with Sustineo to undertake training with NARI staff without APR input.

The objectives of the training were to establish expectations for fieldwork conduct. This included familiarising participants with the:

- Purpose of the survey, the questions and protocols for conduct of the survey
- Approach to sampling, participant identification and issues related to the ethical conduct of research
- Quality control and consistency protocols.

Providing NARI staff sufficient time to practice the survey, identify any issues or inconsistencies with the survey, and build their confidence in the conduct of the survey were also important aims for the training.

The presence of CSIRO and Sustineo staff during the pilots provided further benefits in terms of reiterating the key messages from training. The opportunity to observe NARI staff conduct interviews at the various pilot locations allowed for some of the inconsistencies noted above to be addressed. CSIRO and Sustineo staff were confident that the training provided consistency within the team and the approach taken by APR. This will be reviewed and confirmed after data analysis.

While the conduct of training required a flexible approach due to the challenges noted above, at the conclusion of the training CSIRO and Sustineo staff agreed the training had achieved the core objectives.

The table below provides an outline of the training related activities that were conducted. There was also discussion of comments of the survey and training during informal discussions while travelling and at other points over April 27 and April 28.

Day 1 (April 27)	**Day 2 (April 28)**
9:30am-12:30pm – Training conducted with the four NARI staff.	8:00-10:00am – Debrief with NARI staff on the conduct of the Pilot, reiteration of key points from training and clarification on key questions.
1:30-5:00pm – Pilot of conducted at Ontobura concurrently with the installation of a weather station. Three enumerators conducted a total of five surveys.	1:00-3:30pm – Pilot of conducted at Okapa concurrently with the installation of a weather station. Three enumerators conducted a total of seven surveys.
	Evening – Informal debrief with team over dinner to recap key points.

Overall, training was conducted with a total of four NARI staff. On Day 1, all four staff were present. During the pilot on Day 1, one enumerator did not conduct any practice surveys as they were assisting with the installation of the weather station.

On Day 2, all four staff were able to attend a debriefing session, however one was not able to attend the pilot as they had other management commitments. During the pilot, two enumerators conducted three surveys each. The other enumerator, again responsible for assisting with the installation of the weather station, was able to complete one.

After training was completed Sustineo produced two guidance documents to recap key aspects of the training and to provide guidance on the approach to data entry. These are available at Appendix A and B.

Raw data was collated in excel spreadsheets and responses were checked for consistency between both the Anglo Pacific Research and NARI Staff. The software Package R (R-Development-Core-Team, 2006) was used to analyse the response data and produce the network maps contained in the "*Results*" section of this document.

The survey was undertaken in three rural communities in the eastern highlands of PNG. These communities were located within a 150km radius of Goroka and included Ontobura, Okapa and Ifiyufa (Figure 6.1). A total of 401 surveys were undertaken in these three rural communities, using a paper based survey approach. After careful analysis of the surveys 389 were used in the final analyses. In terms of respondents 53% were male and 47% were female.

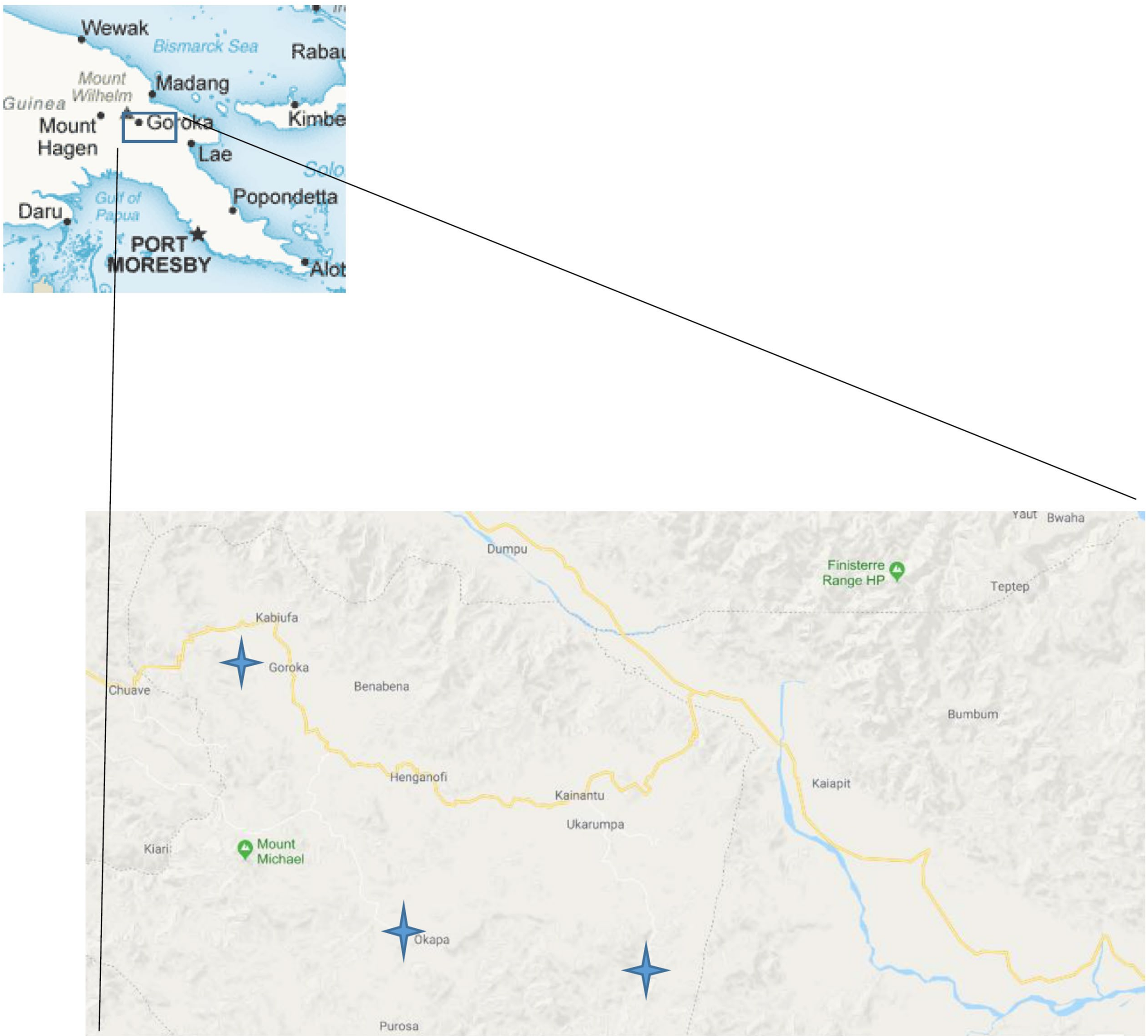

Figure 6.1. Location of the case study region and three villages. (Bottom right – Ontobura, Top Left – Ifiyufa).

Objective 2: Identify new seasonal climate forecast knowledge products to help communities and agencies respond to specific climatic challenges

A literature review and website search were undertaken to determine the new SCF products that may be applicable for use in PNG. The review examined both peer reviewed literature as well as conference proceedings, technical reports and factsheets.

A catalogue of potential products was collated based on the expert knowledge of the project team.

The collated list was tested against the responses from the survey regarding dissemination modes to determine the most appropriate types of knowledge products for use in PNG.

- Activity 2.3: Develop a set of notional SCF knowledge products and test the utility of these within the case study communities identified in activity 1.1. Finalise SCF knowledge products based on feedback.

Objective 3: Establish three new weather stations in collaboration between NARI and NWS

Three automated weather stations we purchased from Instrument Choice based in Melbourne. The loggers purchased were "*Davis Vantage Pro 2*" that included "*WeatherLinkIP*" software and Digital console that allows real-time data displays and calculation of future weather conditions 48hrs in advance. The "*Davis Vantage Pro 2*" weather station transmits weather information by wireless signal to the display up to 300 meters away and tracks several local weather variables, including temperature, humidity, wind speed, wind direction and rainfall totals, and it stores historical data. The sensor suite uses solar power to reduce battery consumption. All of the sensor's electronic components are housed inside of a weather-resistant shelter. The "WeatherLinkIP" allows the automatic uploading of weather data from the weather station to a dedicated field laptop.

The three weather stations were transported to PNG by commercial airlines and then to Goroka via a private freight company. A one-day delay in receiving the weather stations at Goroke did delay the SNA training course at Aiyura. The Weather stations were installed at Ontobura, Okapa and Ifiyufa (see images).

Photo: *Weather station at Ontobura*

Photo: *Weather station at Okapa*

Photo: *Weather station at Ifiyufa*

NARI staff were trained during the installation of the weather station on how to download data onto the fieldwork laptop. A training session was also repeated with community representatives at both Okapa and Ifiyufa. NWS staff were present for the installation of two of the three weather stations. Both NARI and NWS staff were provided software to download and visualise the data. Some training was undertaken with NARI staff to use the software prior to the installation of the weather stations. Data has been sent back to Australia from two of the three stations. Intermittent problems with the Ontobura station has resulted in corruption of the data set. Some efforts have been made to recover the corrupted data but the data logger has been removed and reprogrammed.

As series of time series analysis tools were assessed to see which were appropriate for standalone analysis of weather station data from PNG. After reviewing a number of possible analysis platforms, the STARDEX platform was selected. This was selected over a number of others due to it's ease of implementation, it's use of simple data formats and potential to calculate around fifty seven different climate indices. Due to the short record of data collected from the weather stations, the calculation of statistics was not possible, for this reason the Port Moresby climate data was analysed and presented to NWS staff to determine if the software was appropriate for use by NSW staff.

Objective 4: Understanding how agricultural vulnerability has changed by examining and mapping changes in historical rainfall and temperature variability

The project team were able to obtain a total of 31 climate station records from PNG and West Papua. Prior to undertaking trend analyses on the data, stringent quality controls and missing data assessments were applied. Most of the climate station data have only been operating for several years, with only a few having operated for more than 10 years. In addition, there are a significant number of stations with large periods of missing observations. Consequently, the only way to extract a trend estimate form the viable stations was to fit a statistical model to the data.

Each of the climate statistics (indices) were computed by month or over a whole year. Monthly values were compiled to whole-year averages over the period 1960-2016. Where more than 50 days of data were missing in a year, the indices for that year were set to missing (NA). Whilst there were a total of 31 climate stations with a record length of 57 years only 9 stations had small amounts of missing data.

In addition, one climate station, JAYAPURA SENATANI, was found to have highly anomalous data and so it was removed from the subsequent statistical modelling as it would have had undue influence on the final results.

A Generalized Additive Model (GAM) was used to estimate time trends using the data from the 31 stations. To account for the large variations in topography reflected in the data a bivariate non-parametric mean term was included in the model. A suitable form for the model was found based on minimising the Bayesian Information Criteria (BIC). This resulted in a model which included terms for an interaction between trend and non-parametric terms for location, as well as a linear interaction between trend and the log of altitude.

It was not possible to use a non-parametric form for altitude because of the sparseness of observations across altitudes in PNG. That is, there is a scarcity of climate observation at inland sites in PNG.

Predicted values from the statistical models were used to map the trends per decade across PNG. Ocean areas were masked out of the map.

Objective 5: Developing climate smart response options for farming communities –

A review of existing literature sources as well as conduct targeted community based interviews were used to develop a set of "no regrets" farming options for case study sites in the Eastern highlands province that will be effective in mitigating potential losses during below "normal" (e.g. El Niño) and above "normal" (e.g. La Niña) seasonal rainfall conditions. The team member who undertook the literature review was Dr Michael Bourke. He has been working in this field for more than 35 years and has written much of the literature on this topic. He substantiated the results against local informal interviews run by two in-country partners (Mr. Reuben Sengere's and Ms. Rebecca Amira).

Relevant aspects of the physical environment for PNG agriculture include temperature (altitude is a good surrogate for this in PNG); rainfall (annual and seasonal distribution); soils; landforms; slope; cloudiness; day-length; sunshine; and inundation (short-term or long-term flooding). The best source of data on the physical environment for agricultural production in PNG is the PNG Resource Information System. This Geographic

Information System contains detailed information for 4566 mapping units based on six aspects of the physical environment. However, the database is not publicly available and can only be used by a few people who have received specialist training. It was developed by scientists from the Division of Land Use Research in CSIRO Australia with some data from the Land Use Section of PNG DPI.

A summary of the most important aspects of the physical environment for agriculture in PNG is presented in several sections of the book *Food and Agriculture in Papua New Guinea*. Sections cover: land use, rainfall, El Nino Southern Oscillation, Temperature, cloudiness, sunshine, climate change, soils, landform, altitude, agricultural environments, land quality and the relationship between crops, people and the environment (Bourke and Harwood, 2009).

An excellent overview of climate in PNG is given in the book *Climate of Papua New Guinea* (McAlpine *et al*., 1983). The book is written in such a way that a non-specialist can readily understand it. Detailed rainfall, temperature and other climate data was published in a technical manual (McAlpine *et al*., 1975)[2]. Other books in the same series by the CSIRO cover vegetation, geomorphology, and soils. These books are more technical and hence less accessible to non-specialists.

Information on the population of a region, province, district or local area is basic for any planned intervention. National population censuses have been conducted in PNG in 1966, 1971, 1980, 1990, 2000 and 2011. Demography experts consider that those conducted in 1980 and in 2000 were the most reliable. It has been suggested that the most recent national census in 2011 was not well conducted and that the data is flawed. It is possible to extrapolate population figures from the 2000 census, but there are problems with this. Firstly, there is no consensus on the best figure to use for population growth rate. (This author uses a figure of 2.7% per year, but others use different figures.) Secondly, there are potentially large errors in extrapolating over a 17-year period (2000 to 2017). The alternative is to use data from the 2011 census, knowing that there are strong indications that the data is flawed, particularly for the seven highland provinces. Population data from the 2011 national population census is available on line with data at the following levels: national, provincial, district and Local Level Government (NSO, 2013).

There are many publications on agriculture in PNG[3]. The Mapping Agricultural Systems of PNG database contains detailed information on over 100 aspects of village agriculture in PNG. This is based on extensive field surveys over all PNG in the 1990s. Land used for agriculture was divided into 343 mapping units ('agricultural systems') which were more-or-less homogeneous for six key aspects of agriculture and land use. A monograph (so called 'Working Paper') was produced for each province and these are available on-line. (See Bourke *et al*., 2002 for Eastern Highlands Province). The information in this database is generally still accurate twenty years after the field mapping was completed. This is because the greatest changes in agriculture and land use in PNG took place between about 1940 and 1980. However, there have been some significant changes in agricultural production since the 1990s. Sweet potato production continues to expand at the expense of older staple foods of taro, yam and sago. This is mostly occurring in lowland and intermediate altitude locations (below 1200 m altitude), but it has occurred in the area south of Obura since the 1990s. The other significant change has been in the income from cash cropping, given the depreciation of the PNG currency and inflation over this period. There have also been some changes in sources of cash income, with greater sales of fresh food and static coffee production in the highlands.

Summaries of the most important aspects of agricultural production are given in Parts 2, 3 and 5 of *Food and Agriculture in Papua New Guinea* (Bourke and Harwood, 2009).

Summaries of physical environment, demography, economy, transport, village agriculture, issues and problems were presented for three provinces in the mid-1990s. One of these is Easter Highlands (Bourke *et*

[2] Both books have been digitized. I can provide digital copies to interested persons.

[3] For example, the PNG Agriculture Literature Database, which was created and maintained by the former Land Management Group in College of Asia and the Pacific at the ANU, contains over 17,000 entries on PNG agriculture, land use, nutrition and related topics. The author can provide an electronic copy of this database.

al., 1994). With the caveat that the figures for cash income are now dated, information in this booklet is still valid.

Objective 6: Determination of information/technology/asset gaps and strengths in the dominant farming systems of the case study districts –

A gap and strengths analysis was undertake through informal interviews with NARI, NWS and Office of Climate Change and Development (OCCD). A short series of interview questions were asked of key staff members and compared with other literature that examine capacity constraints within PNG Government organisations (see Appendix D for the interview questions)

Objective 7: Drafting a set of recommendations on research for development questions relevant for climate smart agriculture in PNG –

Based on informal interviews with experts and key institutional staff within NARI, NWS and Office of Climate Change and Development (OCCD) a series of recommendations on research for development questions relevant for climate smart agriculture in PNG were established.

Photo: *NARI survey team*

7 Achievements against activities and outputs/milestones

Objective 1: Building capability of PNG research agencies and rural communities to link to extreme event warnings and regional climate forecasting capability

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
1.1	Identify case study locations in the Eastern Highlands Province to undertake the social network analysis (SNA).	Case study sites identified.	February 2017	Three sites were identified based on proximity to Aiyura and accessibility. The three sites included Ontobura, Okapa and Ifiyura.	NA
1.2	Identify "Tok Pisin" speakers who would be able to undertake the SNA in each location. Develop a draft design of the SNA and test this with on-ground partners.	"Pisin" speakers identified and draft SNA developed and tested.	March 2017	Five NARI staff were identified and resources were provided to cover their time in this project. Resources were also provided to Anglo Pacific Research to secure staff to run part of the survey. A draft English version of the survey was developed and circulated to Sustineo and NARI for comment. The consensus version of the survey was translated into "Pisin" and then translated back to English to see if the meaning had been changed. Some small additional changes were made to a final version of the survey before providing it to Anglo Pacific and NARI to undertake.	NA
1.3	Undertake a training session with our on-ground partners in both undertaking the SNA and collating the data.	Training session with NARI completed.	April 2017	A two day training course was undertaken with NARI staff on 27 and 28 April. Staff were given an opportunity to provide further feedback on the survey and were also instructed in how to undertake the survey, collate the data and enumerate the results.	NA
1.4	Complete the analysis of the SNA data and produce the network information.	SNA analysis completed.	October 2017	The analysis of almost 400 surveys was undertaken using R software and network maps have been produced and are included in this report See pages 33 to 54.	NA

Objective 2: Identify new seasonal climate forecast knowledge products to help communities and agencies respond to specific climatic challenges

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
2.1	Undertake a review of existing operational seasonal forecasts and derivative information that would potentially be available and usable in PNG.	Review of existing SCF systems for PNG completed	June 2017	A review of all existing operational SCF information available for PNG has been undertaken. The list of potential SCF knowledge products is included in this Final Report. See pages 55 and 56	NA
2.2	Catalogue useful knowledge products and compare these products with the results from the SNA regarding dissemination modes. .	List of appropriate SCF information developed.	June 2017	A review of all existing operational SCF information available for PNG has been undertaken. The list of potential SCF knowledge products is included in this Final Report. See pages 55 to 60.	NA
2.3	Develop a set of notional SCF knowledge products and test the utility of these within the case study communities identified in activity 1.1. Finalise SCF knowledge products based on feedback	List of notional SCF products tested against survey information.	October 2017	The results from the SNA survey regarding the format of information needed to support agronomic decisions was used to subset the existing SCF products to a final set of products.	NA

Objective 3: Establish three new weather stations in collaboration between NARI and NWS

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
3.1	Purchase and transport three automated weather stations to the case study locations.	Weather stations purchased.	February 2017	A number of companies were approached to supply weather stations. A decision to purchase the weather stations from Instrument Choice was made based on original quote and the digital display option for the weather station data.	NA
3.2	With NARI and NWS locate and establish the weather stations in each community.	Weather stations installed in three locations.	April 2017	Weather stations were installed with NWS and NARI staff at Ontobura, Okapa and Ifiyufa. Due to proximity NARI staff were provided with a fieldwork laptop to download the data from all three weather stations. Data download have been undertaken on three occasion from each weather station.	NA
3.3	NWS to train staff from NARI and selected community representative to maintain the weather stations and download the climate data.	NWS and ANRI training completed	April 2017	NWS and NARI staff were trained to install, maintain and download data from the weather stations. NARI staff were given informal training on the weather station installation over a two day period on 28 and 29 April 2017. Instruction manuals and software were shared with NARI and NWS staff and informal training was undertaken over the two days in data downloading and trouble-shooting.	NA
3.4	CSIRO and NWS staff to develop automated software to develop agriculture specific information products.	Analysis software identified for use.	September 2017	A series of software packages were identified for potential use to analyse the station data. Elements for the STARDEX software package was selected and coded.	NA
3.5	Software tested on weather station data.	Software testing complete	October 2017	Goroka and Port Moresby station data was used to test software and presented to NWS partners.	The time series data was not of sufficient length to test software. Instead the Goroka and Port Moresby station data was used and presented to NWS partners.

Objective 4: Understanding how agricultural vulnerability has changed by examining and mapping changes in historical rainfall and temperature variability

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
4.1	Download data from the existing 39 weather stations in PNG. Undertake quality control and error checking on sites with sufficient record length.	All available contemporary PNG weather data downloaded.	May 2017	All data from the available station network has been downloaded and error checking and missing data infilling was completed.	NA
4.2	Download relevant NCEP gridded data and statistically enhance the resolution using quality controlled weather station data.	NCEP re-analysis data downloaded for PNG.	May 2017	A statistical modelling approach was employed to generate the continuous climate surfaces.	The gridded data from NCEP was not used given the poor representation over PNG.
4.3	Develop a list of climate indices relevant for PNG agriculture based on local expert opinion.	Climate indices identified.	May 2017	A list of climate indices was developed using available temperature and rainfall data. See table 8.4.1.	NA
4.4	Compare the change in frequency of these climate indices for two discreet periods i.e. 1960 to 1984 and 1985 to 2015.	Climate Indices analysed for trends	July 2017	A trend analysis was undertaken across the whole historical period 1960 to 2016.	The analysis of changes between the two periods was not possible given the paucity of data. The large gaps in daily data meant that insufficient data existed for each period. Instead a trend analysis was undertaken across the whole historical period 1960 to 2016.
4.5	Produce a series of anomaly spatial maps that plot the difference in the climate indices across the two periods.	Maps produced for climate indices.	July 2017	Maps were produced for the trends in relevant climate variables for the period 1960 to 2016. See figures 8.4.2 to 8.4.12	Climate data was to sparse to produce analyses for the two different periods.

Objective 5: Developing climate smart response options for farming communities

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
5.1	Review existing literature sources as well as conduct targeted community based interviews to develop a set of "no regrets" farming options for case study sites in the Eastern highlands province that will be effective in mitigating potential losses during below "normal" (e.g. El Niño) and above "normal" (e.g. La Niña) seasonal rainfall conditions.	Review of farming options complete.	October 2017	Dr Michael Bourke undertook a literature review of no regrets farming options to respond to the three year types. These options were tested with local communities to determine feasibility. The review is included in this Final Report. See pages 77 to 87.	NA

Objective 6: Determination of information/technology/asset gaps and strengths in the dominant farming systems of the case study districts

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
6.1	Undertake "Gaps and Strengths" analysis based on expert knowledge sources, information from the SNA survey and workshop activities.	A gaps and strengths analysis undertaken.	October 2017	A series of informal interviews were undertaken with NARI, NWS and OCCD to identify important limitations and strengths in existing farming systems extension and research. The analysis of the interviews is contained in this Final Report. See pages 88 to 93.	NA

Objective 7: Drafting a set of recommendations on research for development questions relevant for climate smart agriculture in PNG

No.	Activity	Outputs/ milestones	Completion date	What has been achieved?	What has not been achieved?
7.1	Undertake informal interviews with experts and key institutional staff to identify a set of recommendations on research for development questions relevant for climate smart agriculture in PNG.	Recommendations delivered.	October 2017	A series of informal interviews were undertaken with NARI, NWS and OCCD to identify important limitations and strengths in existing farming systems extension and research. The analysis of the interviews is contained in this Final Report. See pages 88 to 93.	NA

Photo: *Sweet potato sold at a local market.*

8 Key results and discussion

In the sections that follow we present a summary of the of the seven broad research activities; we provide an overview of the SNA survey results, some data from the weather stations, results from the software development and analysis, a review of potential SCF products for PNG and trend mapping. In addition we also present a gaps and strengths analysis as well as some recommendations.

8.1 Social Network Analysis

Although SNAs provide overview of network behaviour and properties, they do not look are why that behaviour exists, or how people apply knowledge. This method limitation is discussed in the discussion section, and recommends qualitative methods to capture how different groups use and absorb knowledge for long term impact.

Further details on the survey questions, analysis, challenges, and lessons from training are presented in Appendices A and D. Appendix E includes summary tables of data collected, and Appendix B includes all maps not presented in this report, largely village specific ones.

Reading the maps

The thicker the arrows are in trust maps, the more exchanges of information. The larger the circle, the higher the degree of connections that group has.

Knowledge and information are used interchangeably for the purposes of this report.

The following legend applies to all trust and information flows maps (8.1.1).

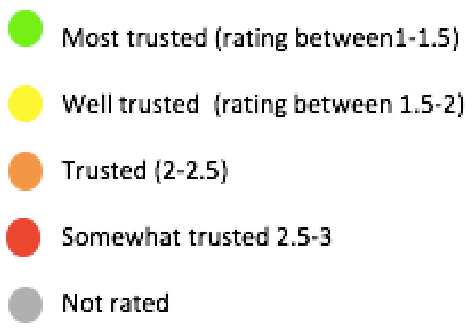

Figure 8.1.1. Legend for information flows and trust maps

The types of weather information with sources for information maps are one-directional, so there is no measurement of the strength of the link. Rather, these maps just show relationships between what respondents felt was the most important kind of climate information, and which institutions they felt were the most vital sources of information.

Major cohesion measures in a social network are presented in Table 8.1.1. These measures were used to analyse and discuss the behaviour of the trust and information flows networks. Trust ratings were asked *after* respondents were asked to nominate what sources they trust – so therefore some of the groups where people said they obtained information and/or passed information to, were not rated when people were asked to rate trusted sources of information (for example, youth and women).

Table 8.1.1. Overview of social network measures and how they applied to this topic of this SNA, based on Hawe *et al.* (2004); Cvitanovic *et al.* (2017)

SNA Measure	Overview	How measure was used analytically
Actors	Individuals in a network, or collective units	As this was socio-centric analysis, we grouped individual survey respondents into major categories
Distance	The number of lines between one group to another	Look at longest distance between groups, to gauge if outlying groups should be of concern for future SNAs.
Cliques	Sub-groups that are tightly connected with each other, and no other network member is connected to all members of the sub-group	Identify any sub-groups that exchange knowledge with each other
Centrality	Who the most prominent groups in a network – i.e. who receives and shared the most information	Identify most prominent groups in information flows.
Degree centrality	The sum of all actors connected to a specific group	Gauge which actors are most connected to each other
Closeness	This is based on distance between one actor and another. If distance is no more than one group, then there is a direct theoretical information flow between two groups	Identify groups close to each other
Betweeness	This identifies the most 'powerful' actors in connecting other groups with each other	Identify influential players in knowledge flows

Structure

The following section outlines the SNA method used and the approach taken in this research activity. The three major findings focus first on levels of trust at an aggregate level, and from a farmer-centric level, second on types of SCF information and main sources for that information, and third gender similarities across the networks. The final section discusses the relevance of these findings for future SCF dissemination activities, and recommends options for up-scaling the SNA.

A guide to the sub-groups from the survey aggregated to create meta-groups for analysis, and the SNA cohesion measures used to analyse the maps, is in Appendix 1. Levels of trust and farmer-centric findings.

Key messages

Influential groups and levels of trust

- Community, church and family consistently most trusted group across all villages. Church was less prominent in Ifiyufa, but still trusted.
- Community are largely recipients of knowledge. Family and church are two-way knowledge facilitators.
- The Church is highly trusted and influential, but not a direct recipient of government knowledge.
- Sub-networks exist that share a lot of information, frequently, with each other.

Farmer centric specific analysis

- Farmers highly trust the major groups: church, community, family, and media.
- Family has high centrality – it receives and influences other groups. This makes family a core target group for disseminating SCF.
- Government and family did not share close relations, with information usually going through another group between government and family.

Implications:

- Farmers can be reached by delivering SCF to different village groups.
- SCF is likely to be transferred through informal communication networks, and thus reliability of that transfer needs to be enhanced by ensuring that SCF is clearly articulated in a non-technical manner and understood as it is passed on.
- Farmers trust many groups. This means that SCF information needs to be delivered to other groups in a consistent way to avoid farmer confusion.
- Governments do not seem to receive community information. This may pose long-term challenges to adapting government messages to community needs.
- Church, community and family also imply verbal communication, which again lends to risk of information being miscommunicated.
- There are strong sub-group connections between church, community, family, and Wantoks. SCF information can be targeted at core groups.

Trust analysis

Figure 8.1.2 shows the overall social networks for all villages aggregated into one map. Table 8.1.2 summarises the findings for each of the major SNA measures. The figure shows that government was the most trusted source of information, followed by church and community groups, and family.

Wantok levels of trust varied between villages, but was trusted less than the three most central groups. The most central groups are: church, community, family.

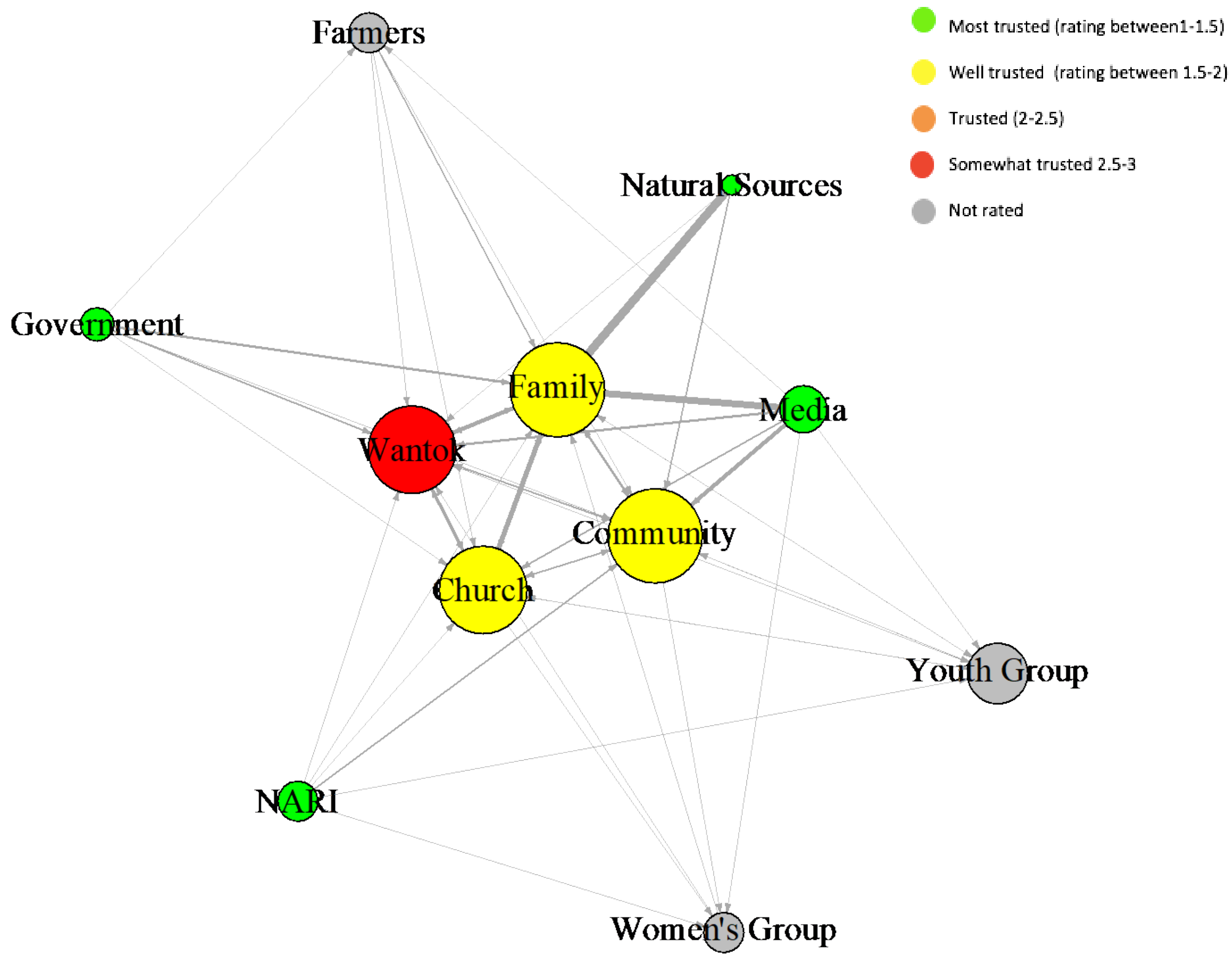

Figure 8.1.1. All villages, levels of trust and number of exchanges

Family, community and the church were very trusted by all groups in the network. Church and family were close to other groups with information flowing directly between those groups rather than going through intermediary groups. Community groups overall were trusted, ***but tended to be recipients rather than disseminators of knowledge***. This was particularly clear in Okapa and Ifiyufa.

The family, Wantok and church groups were prominent in receiving and disseminating information, but the most trusted group was government. While government was the most trusted information source, it was not a major player in two-way information exchange and did not have high centrality in the network. ***Governments was perceived as a disseminator, rather than recipient of knowledge. Communities are not direct recipients of government knowledge, with greater distances between both groups than between government and family, for example.***

Government distance to the church differed between villages. In Ifiyufa, the Government agencies group was most trusted, and had a direct link to the church. In Okapa and Ontobura, the knowledge from government had to go through another group first (community) before reaching the church. Despite the distance between government to church links, church was still trusted in all communities. Across all villages, the church was either very or mostly trusted, and had centrality, making it a well-connected group in the network. This indicates that ***the church is both a knowledge receiver and disseminator – making them influential in the network. Government is highly trusted, but the information between government and church may go through another group first.***

Cliques between the family, church, Wantok, and community groups show a sub-network of information flows. Information flowed frequently and directly between sub-network groups, showing low distance between groups. Each group in these cliques then influence smaller groups, such as women's or farmers. **Cliques demonstrate the tight connections between family, church, Wantok, and communities – noting that communities often receive knowledge at village specific levels.**

The major difference between villages was the level of trust towards Wantok groups, with Ifiufa trusting Wantok the least. **This suggests that Wantok groups provide an important means of disseminating information within the target villages, although the levels of trust vary.**

Overall, family, community, and church groups were consistently well trusted and prominent in relation to two-way knowledge exchangers, although to a slightly less extent in Ifiufa (Figure 8.1.4). Respondents actively received knowledge from government, and then exchanged it with other groups, organisations, and family/community members. ***Knowledge information could follow a 'trickle down' format from government to key family and church leaders, who then disseminate to the broader village (for example, farmers and community groups).***

A summary of the SNA cohesion measures for the trust analysis is in Table 8.1.2.

Table 8.1.2. SNA cohesion measures in trust analysis maps

SNA Measure	Findings for trust maps
Actors	Most trusted actors are family, church, community. Government is most trusted of all – but note it is not as central as other less trusted ones. Government consistently outside the network in all villages, but highly trusted.
Distance	There is a lot of distance between government and community (often through one group). Church and family have short distances with most groups – indicating their influence.
Cliques	Frequent cliques were found across all villages between Wantok, community, family, church. These groups often had direct information flows without going through other groups.
Centrality	Family, church and community. Note church had less centrality in Ifiufa
Degree centrality	The cliques above identified the three most connected groups.
Closeness	Distance was low between cliques, noting direct information flows. Governments, although highly trusted, had longer distances to reach some groups, notably community.
Between-ness	Families are particularly powerful – they receive knowledge from most trusted groups and also disseminate it.

Farmer-centric analysis

This section presents findings from analysis focused on farmer's perception of their role in the network. Farmers are a particularly important social group for rural development in Papua New Guinea.

Understanding how climate behaviour between seasons and developing capacity to use that knowledge to improve production practices is essential for rural development (Cobon *et al.*, 2016).

This analysis is based on Figure 8.1.3 that shows the overall network map on farmers trust towards other groups.

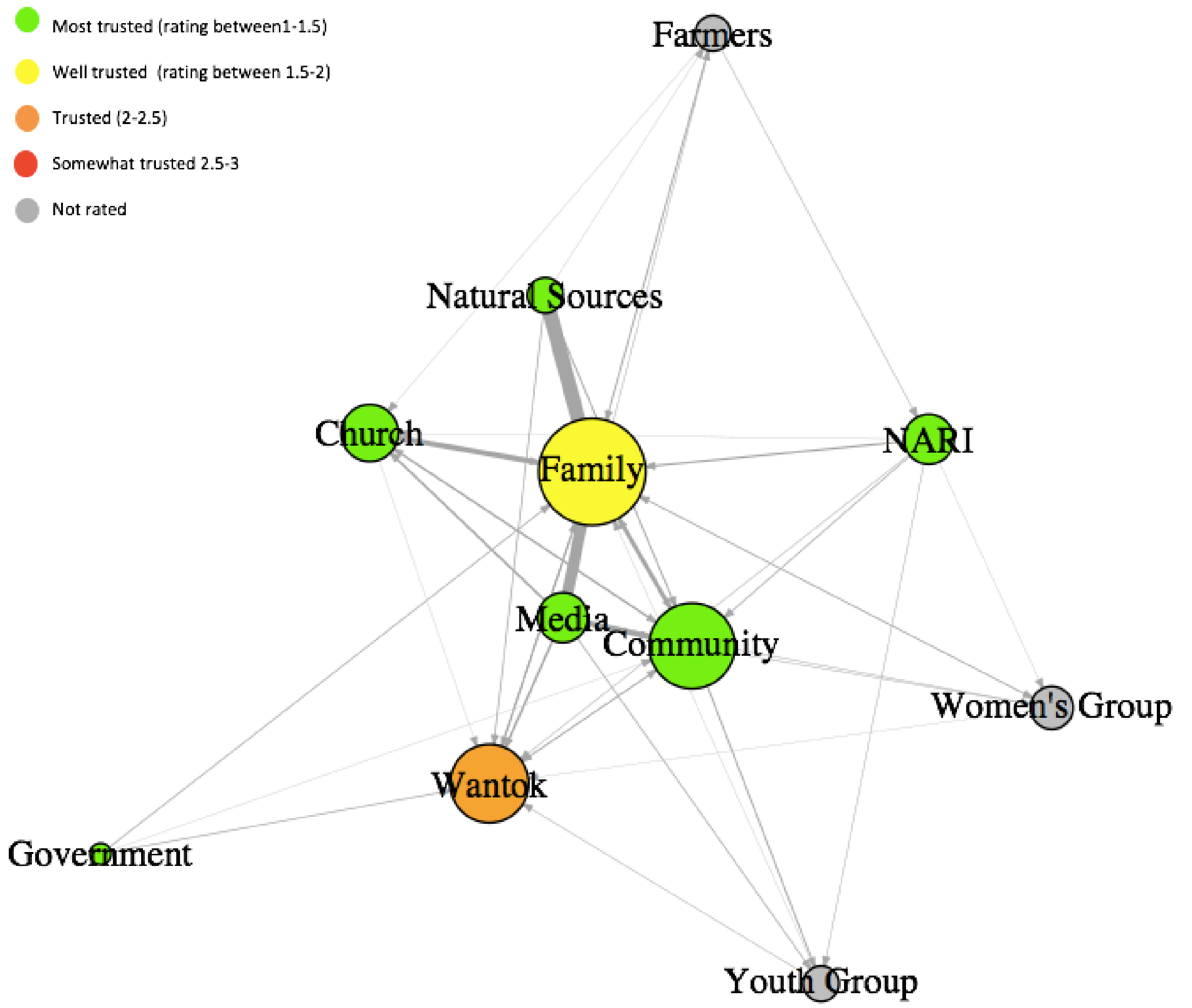

Figure 8.1.2. Farmer-centric, all villages social network map

Farmer's showed relatively high levels of trust towards most groups, both at an aggregate and at a village level. Farmers trusted community, media, and church the most, with Wantok and family being second most trusted. Two new groups emerged as highly trusted: ***agriculture extension officers and media.*** Media was central to the network, agriculture extension officers had less links and influence.

Agricultural extension officers and government officers were highly trusted, but not central to the network. There was a long distance between government agencies and family, with information travelling through one or more groups. ***Given government is highly trusted, but families are highly influential, this distance might present limitations for transferring official government information to farmers. This can be mitigated through the fact that farmers trust multiple sources, some of which are less distant from government.***

Media emerged as a highly trusted and central group in the farmer network. This is a different result from the all village maps (Figure 8.1.4).

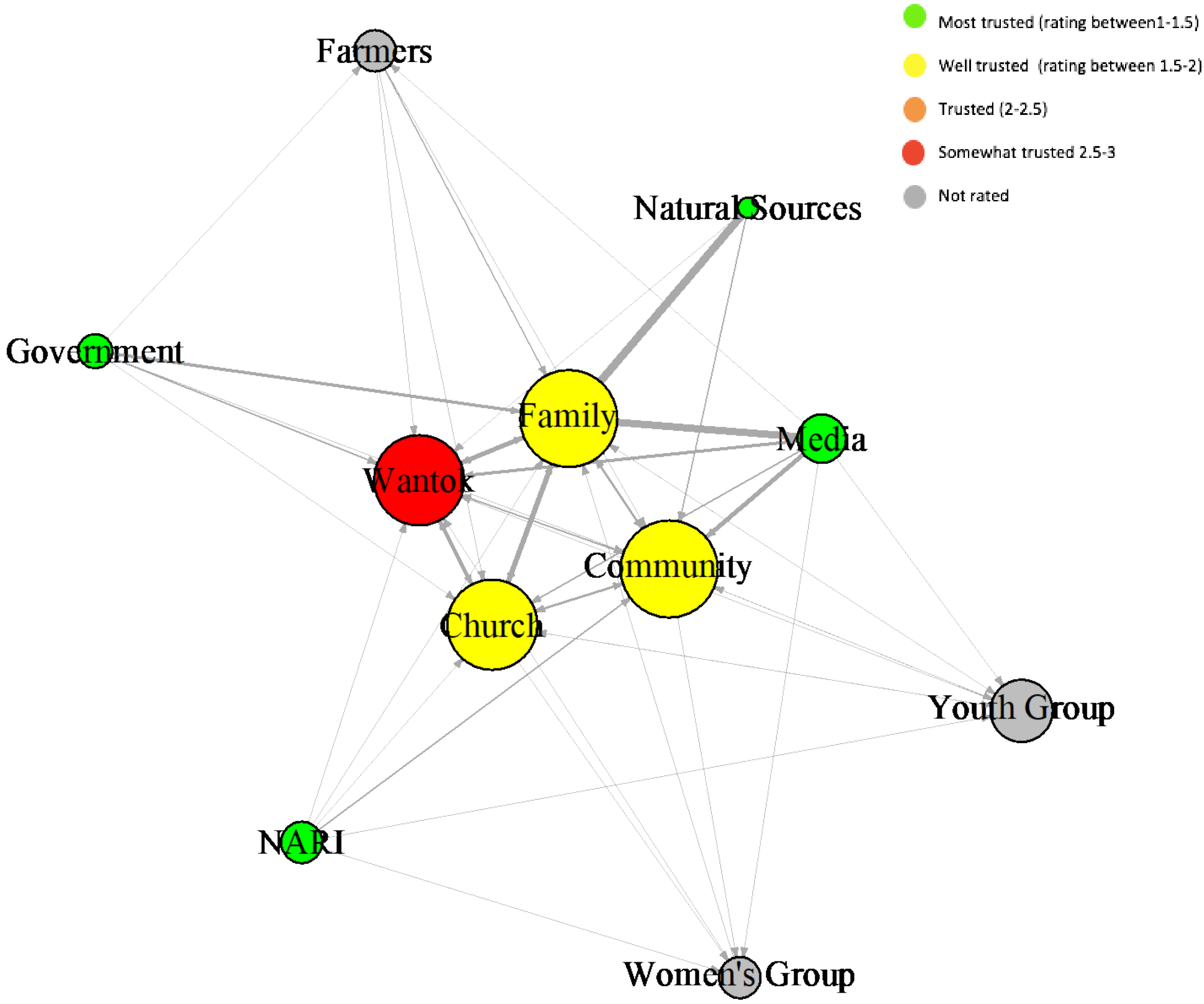

Figure 8.1.4. Farmer-centric, all villages social network map

Across all villages, media was perceived to be a highly trusted source of information with relatively strong links to all other trusted groups. This shows that ***media could be a useful initial portal for disseminating information.***

It is worth noting that government agencies were not close to media. For example, in Figure 8.1.4, government agencies and media directly channel information to communities, but government and media are separated by the community groups. ***This might cause conflict for farmers – both sources are trusted, but it is unclear if there are consistent SCF information between both groups being shared.***

Major cliques exist between church/media/family, and community/media/church. These cliques also had high centrality, making them influential in knowledge dissemination for farmers.

Natural sources were highly trusted, but were not central to the network. The 'natural sources' group relates to observing and learning from weather behaviour.

Table 8.1.3 summarises the main SNA measures found in the farmer-centric analysis.

Table 8.1.3. SNA Measure and summary of farmer-centric analysis findings

SNA Measure	Findings for farmer-centric maps
Actors	High levels of trust for community, media, church, and agriculture extension officers.
Distance	Large distance between government and family. This is important as family is a highly influential group, and government is highly trusted – but information does not flow directly.
Cliques	Similar to previous maps, community, family, and Wantok were linked with each other. Media added an additional group to triad cliques.
Centrality	Family highly central – receives and delivers a lot of information to different groups.
Degree centrality	Dominant actors have numerous connections. Government agencies and agricultural extension officers less connected.
Closeness	Family is distant knowledge recipient of government knowledge – usually going through two groups before reaching family.
Betweeness	Community and Wantok groups are intermediary groups for transferring knowledge from government. Family group is highly connected.

General themes from trust and farmer centric analysis

The major difference between the two analyses was the presence of media (i.e. radio, television, newspaper and sms) and agricultural extension officers in the farmer analysis. Both these groups were highly trusted, but extension officers were more distant in the network. This presents a question on the value of engaging with media to disseminate SCF: it is clearly central and highly trusted by farmers, who are end users of this knowledge. However, they are less important in the broader network.

There needs to be a consideration into consistency of information provided to different groups. Farmers highly trust community, but community received inputs of information from media and government, which do not seem to interact much. It is important to understand if there are competing types of information being provided from media and government to the community. Conflicting information might require communities to make a call on what source to trust most.

Cliques are present across the village specific and the overall social network. Cliques could be targeted as central groups that can deliver information to outliers in the networks, such as women's groups or farmer's organisations.

In future surveys, there should be a discussion on whether it is valuable targeting specific groups to conduct group-centric analysis. Ifiyufa, for example, had just enough numbers of farmers in the sample to conduct a farmer-centric analysis. The groups created for this analysis, such as community, were an amalgamation of many other groups provided by respondents, such a sports teams, music groups. Amalgamating into major group categories at the data collection stage would simplify the analysis.

It was interesting to find that the church was very trusted, but Wantok was somewhat trusted (Figure 8.1.4). The church is a common social gathering place for multiple sub-groups within the network, which are more trusted and influential (such as family and community groups). Leveraging from the church as a social institution that brings other groups together could provide a platform for disseminating SCF information and products.

Sources and types of seasonal climate information

Key messages

Types and sources of information:

- Wantok is not seen as important source, and has limited information on SCF
- Farmers were not perceived as SCF information dissemination channels (Figure 8.1.3).
- Family, community, church seen as important to obtain different types of SCF information.
- Drought early warning is most important SCF information needed, and is most sourced from media, church, community, and family.
- Rainfall (daily, weekly, monthly, seasonal), and temperature (weekly, daily) are second and third most important.
- Cyclone warning information is sourced most from extension officers, the media, and community.
- In Ontobura, different types of information (daily temperature, monthly and weekly rainfall) seems to be best sourced from government agencies, media, farmer organisations, and agriculture extension officers.

Implications for scale up and disseminating technical outputs:

- Focus on village specific networks and target outputs accordingly, as different villages will have different ways of disseminating knowledge
- Farmers are absorbers of knowledge, not disseminators
- Follow up with qualitative questions to explore why the villages are different regarding what sources of information are sought and from who

Figure 8.1.5 and Tables 8.1.4 and 8.1.5 show the types of information different groups disseminate, and how important those groups are. The closer to the centre a group is, the more important it is for disseminating information. Figure 8.1.5 shows the overview of the types of information and most important sources to get that information.

Table 8.1.4 and Table 8.1.5 summarise the most important groups and types of information for all villages. The central groups found were: family, community, church, media, and agriculture extension officers. These groups were found to be the most important ones for disseminating information on:

- Rainfall (daily, weekly, and seasonal forecasts)
- Temperature (daily, weekly forecast)
- Drought early warning information

Table 8.1.4. Most important sources of information, all villages

Source of Information	Total No. of Times Identified by Respondents (All Surveys)
Family	140
Church	118
Community	79
Media	73
Wantok	61
Youth Group	39
Natural Sources	32
Government Agencies	26
Farmer/Farmer Organisations	25
Women's group	18
Agricultural Extension Officers	16
None	16
Traditional Knowledge	11
TOTAL	**654**

Table 8.1.5. Most important information, all villages

Type of Information	No. of Times Mentioned by Respondents
Drought early warning information	162
Rainfall (seasonal forecast)	135
Rainfall (daily)	129
Rainfall (weekly forecast)	60
Daily or weekly rainfall and temperature forecast	58
Temperature (daily)	52
Other	48
Rainfall (monthly forecast)	37
Temperature (weekly forecast)	34
Cyclone early warning information	7
Cyclone early warning information	7
TOTAL	**722**

Some information types only reached certain groups – these information types are the outer blue boxes in the network. For example, cyclone early warning system information was perceived to be best accessed from agriculture extension officers, communities, and media.

The centrality of these groups aligns with the previous findings, that show that community, church, and family are most trusted and influential in the network. Figure 8.1.5 shows that these same groups are perceived to be important sources of different SCF information. ***As such, the findings show that community, church, and family are trusted and perceived to know about different climate information.***

The outlier groups, government, natural sources (observing nature), Wantok, and farmers/farmer organisations, represent groups that were not frequently mentioned as important sources for specific types of information. For example, see 'farmer/farmer organisations' and their link to drought early warning information in Figure 8.1.5. This distant connection shows that few survey respondents thought that farmers were a good source of information only for drought early warning systems. Farmers were not linked to other sources of information. ***This shows that farmers are not perceived as disseminators of SCF information.***

The legend used for the types and sources of information maps is as follows:

Table 8.1.6. Caption for information types and sources maps

Colour/Abbreviation	**Explanation**
(grey)	Source of information
(blue)	Type of information
D. Rain	Daily rainfall forecast
M	Monthly
S	Seasonal
D/W	Daily or weekly
E.W	Early Warning

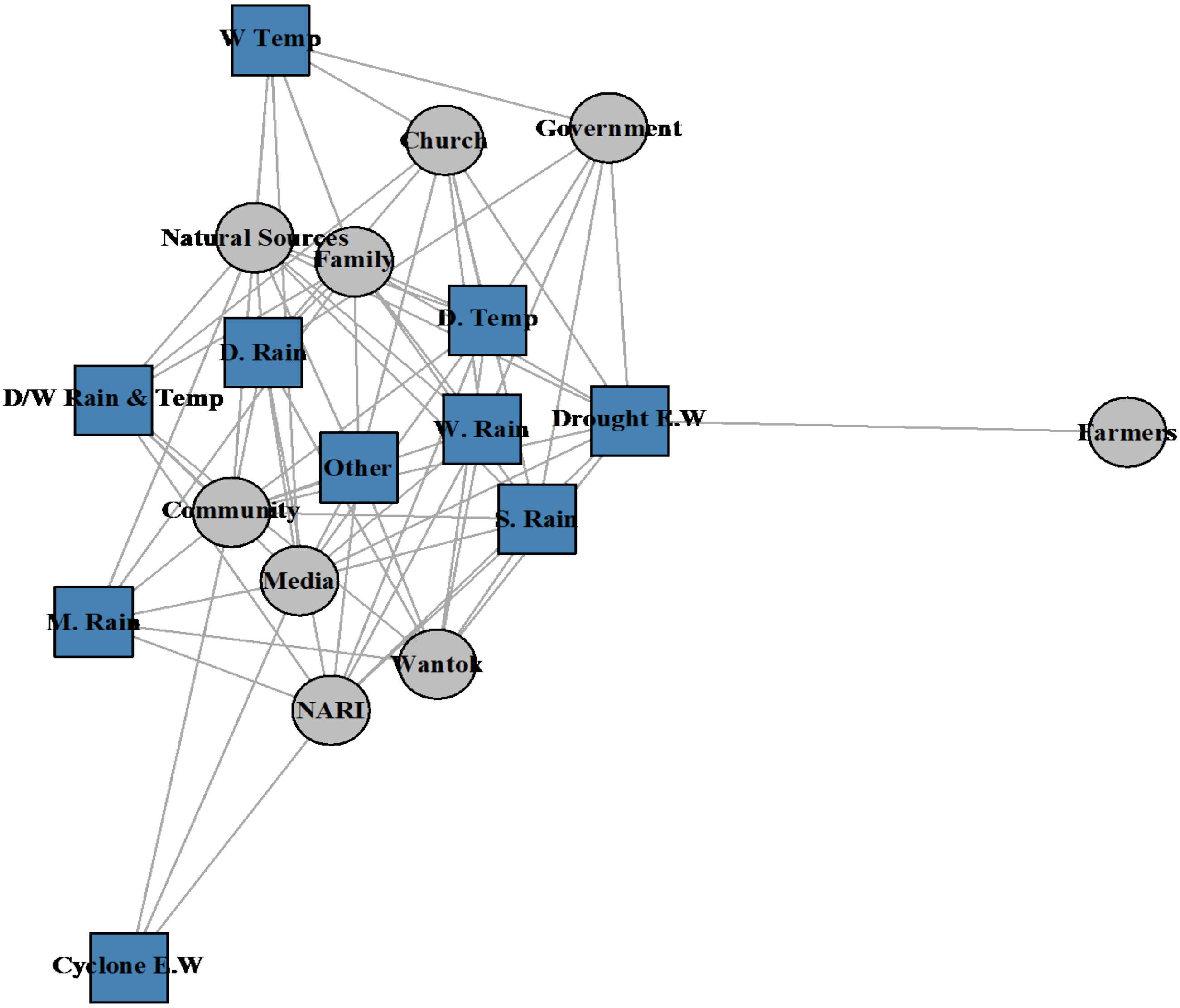

Figure 8.1.5. All villages types of information and most important sources

Village comparisons

Village specific maps show different information flow behaviours, unlike the previous trust-based maps. These village differences provide a nuanced look at how different groups disseminate different type of SCF information. ***These village differences are worth considering in targeting the dissemination of technical outputs, as uptake might vary between villages given the different perceived roles of different groups.***

The most notable differences were found between Okapa and Ontobura. The main difference lay in the centrality of groups. For example, Okapa (Figure 8.1.6) reflects the common finding that family, community, and church are highly influential and exchange different types of knowledge. Outlier groups are farmer organisations, natural sources (learning from observation) and agricultural extension officers.

However, the findings for Ontobura were contrasting (Figure 8.1.7). Family, community, and church are perceived as most useful sources only for weekly temperature, drought early warning information, and rainfall (daily and seasonal forecast). Different types of information (daily temperature, monthly and weekly rainfall) seems to be best sourced from government agencies, media, farmer organisations, and agriculture extension officers.

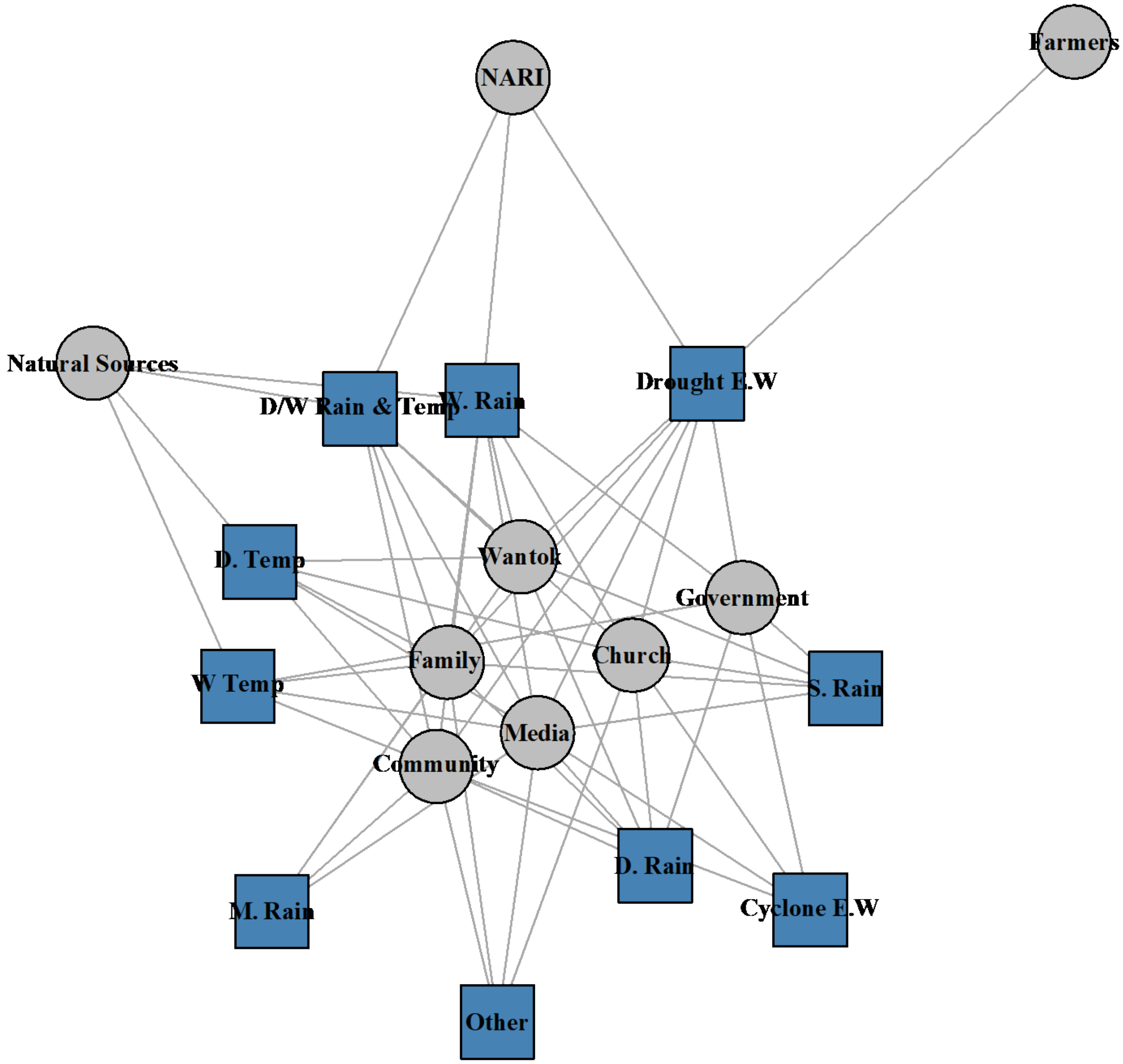

Figure 8.1.6. Okapa types and sources of information

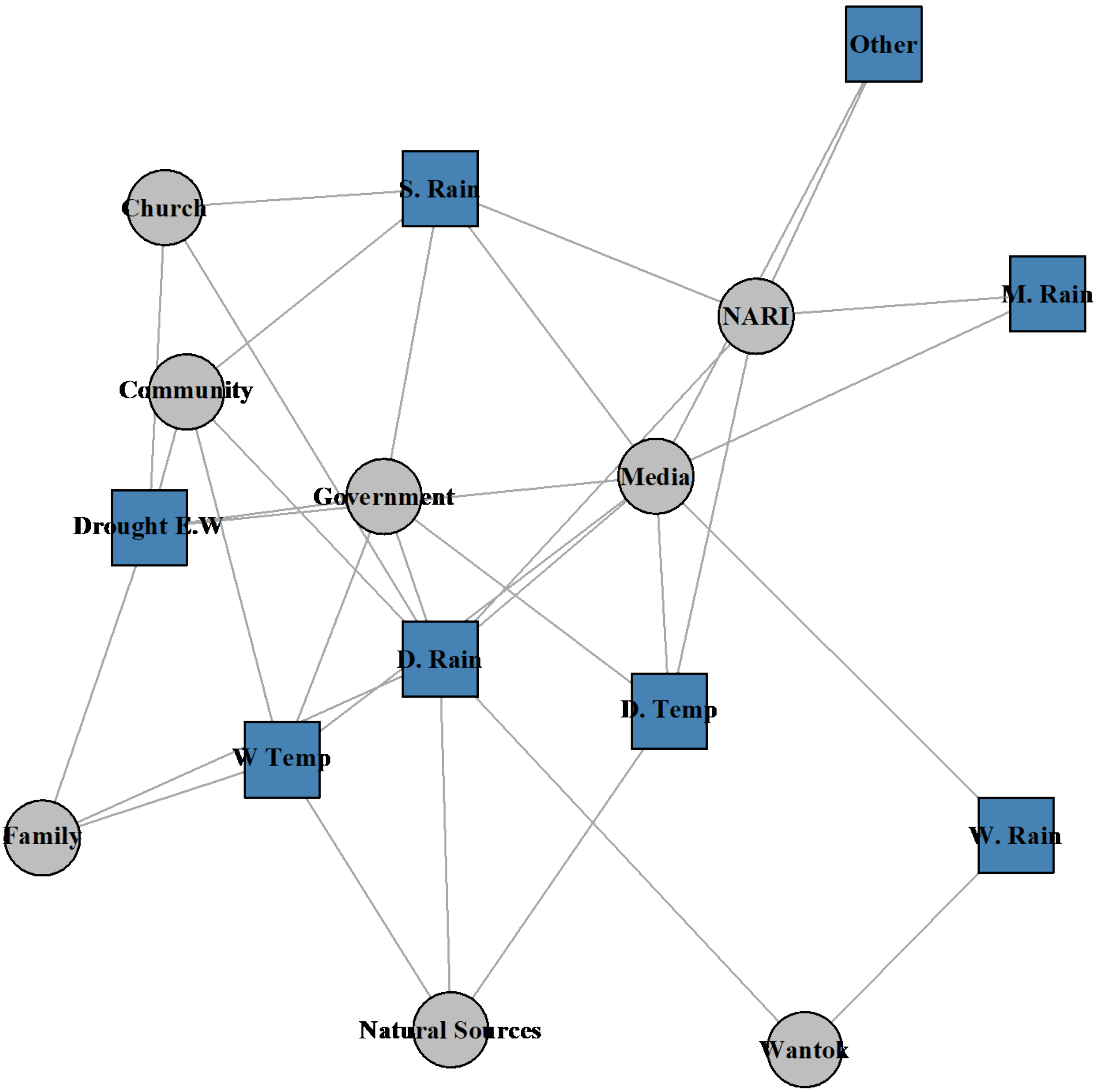

Figure 8.1.7. Ontobura types and sources of information

General themes from sources and types of information

Linking the types of SCF information produced to relevant groups perceived will be very important for dissemination. A mapping exercise of different types of SCF information that will be produced with the most relevant group for disseminating that information would allow an understanding of targeting dissemination of technical products. For example, rainfall and temperature information is sought from multiple groups – so targeting the trusted groups and cliques presented in the previous section would help disseminate this information. Cyclone or drought warning information were found to be best sourced from certain groups (farmers, media, agriculture extension officers, community). Where core information is best sourced from only a few groups, specific strategies for working with those groups should be developed.

There is a need to consider what information is disseminated by what groups at the village level due to some important differences. A deeper look at the village level – especially qualitatively – as to why different sources are perceived as more important than others is required. For example, quantitative surveys capture information flow behaviour, showing between Okapa and Ontobura, farmers disseminate very different information. However, a survey does not explain why that is happening. A well designed qualitative study (after the SNA findings have identified the behaviour of the network) would reveal the reasons behind the different farmer roles between villages, and seek to identify the nuanced differences between villages that influence the uptake of information.

Consistent with the trusted social network maps, family, church and community were central to the network. This confirms that these groups are highly trusted and good trusted sources for a range of SCF information. ***Drought early warning information*** is, on average, most important for all villages, and is sourced from family, church, community, and media.

Gender analysis

Key messages

- No major differences between males and females regarding overall trust. Both sexes highly trusting of most groups.
- Males trusted family more than females.
- Similar cliques between church, community, and family are present across both sexes.
- There is a stronger clique between Wantok-family-community for males.
- Some differences in the sources of information. Males placed farmers and NARI as central sources, whereas women had them as only relevant for some information. Females saw family and community as more central.
- The survey does not reveal how SCF is used to inform agricultural decisions. This provides opportunities for future surveys.

The gender breakdown from the survey is contained in Table 8.1.7

Table 8.1.7. Gender breakdown, total and village specific

	Male		Female		Total
	No.	*%*	*No.*	*%*	
All Surveys	181	53.4%	158	46.6%	339
Ifiyufa	68	56.7%	52	43.3%	120
Okapa	59	52.7%	53	47.3%	112
Ontobura	54	50.5%	53	49.5%	107

Overall, there were no major differences between the groups that males and females trusted. Both sexes, across all villages, followed similar trust and network cohesion structures (Figure 8.1.8 and 8.1.9). Both sexes highly trusted community and the church. Males placed higher trust on families than women.

Wantok was positioned differently between the gender specific networks. Males trusted Wantok less, but it was a more central group. The centrality of Wantok meant that information flowed directly in and out of that group, and was close to other groups (Figure 8.1.8 and 8.1.9). Different behaviour is present in the gender network. Wantok was highly trusted by women, but was more distant in the network.

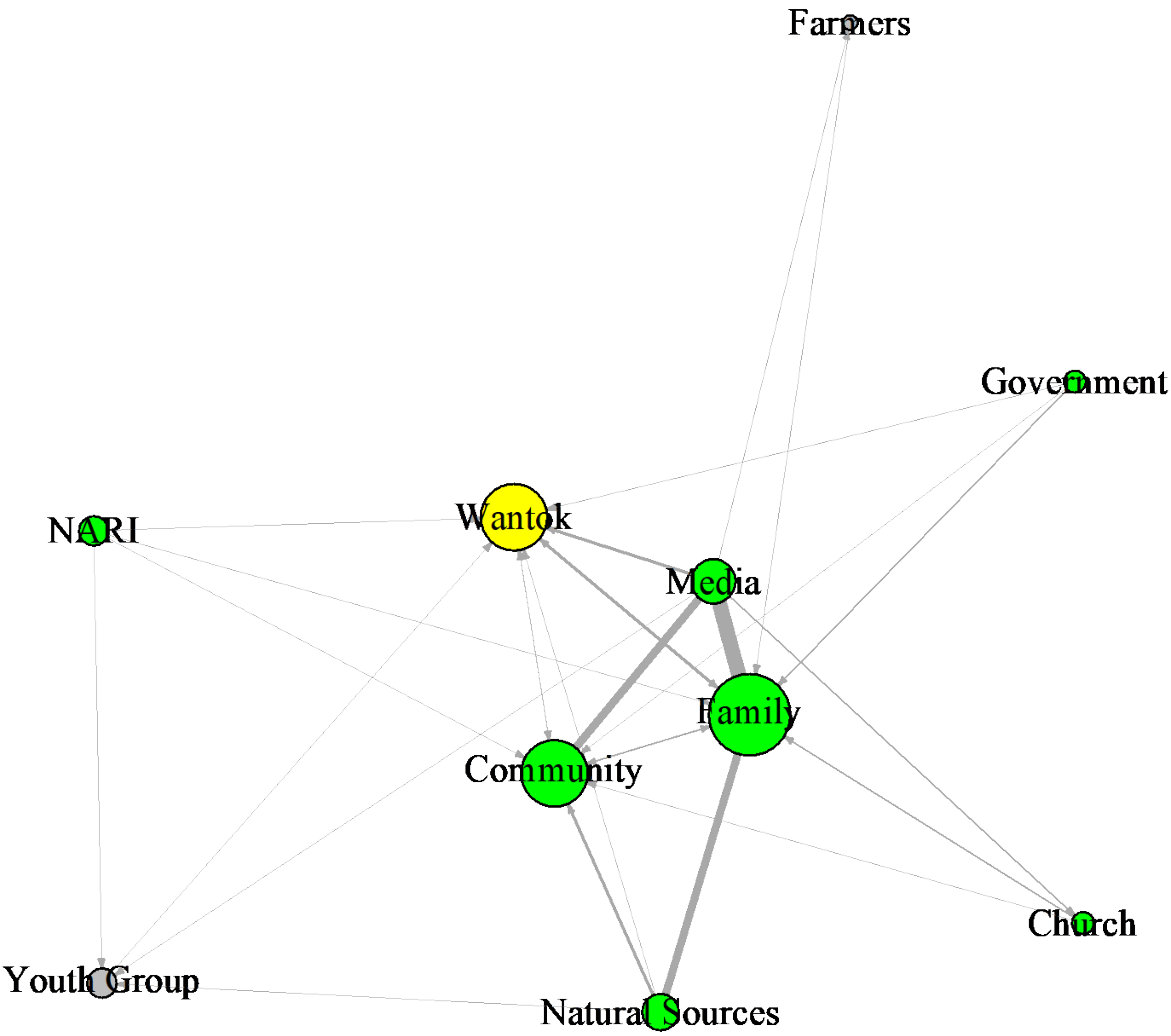

Figure 8.1.8. Males level of trust towards different groups

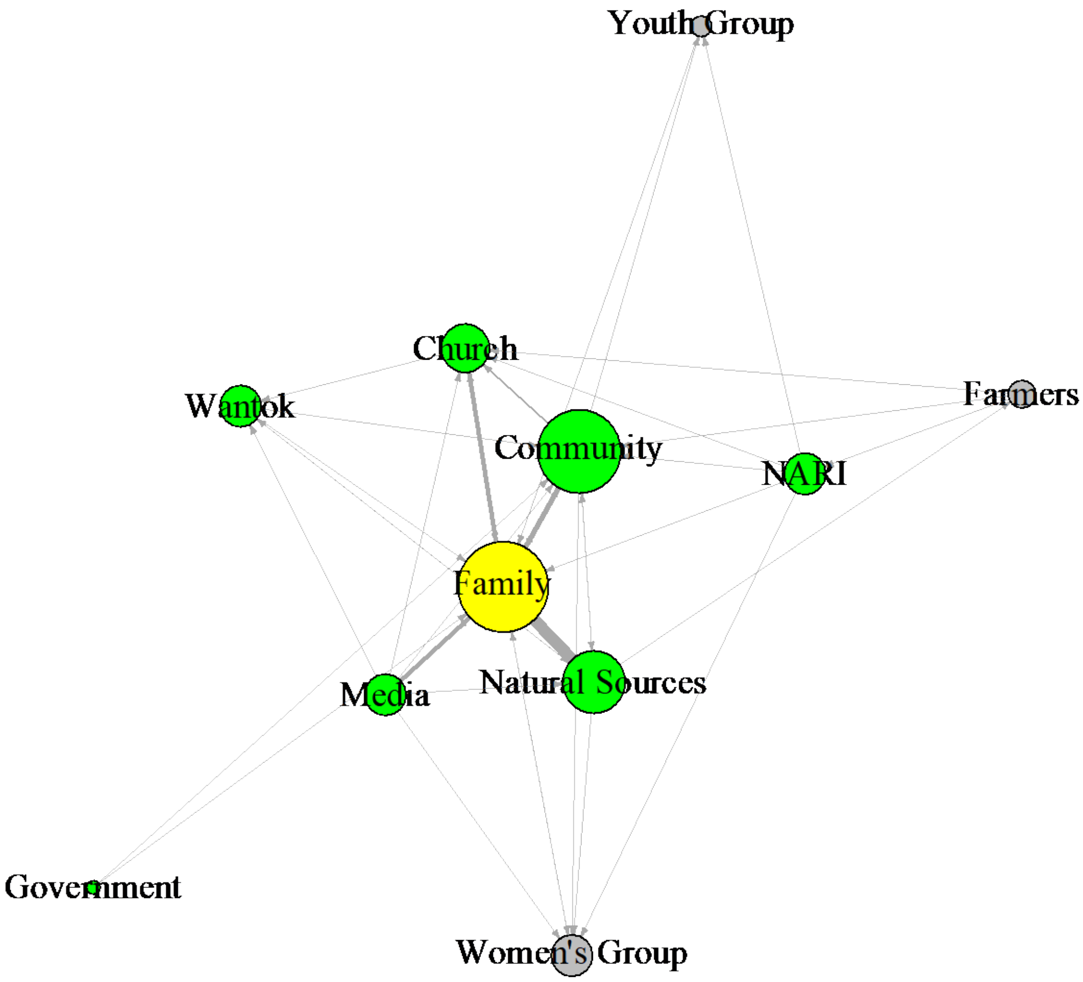

Figure 8.1.9. Females levels of trust towards different groups

Information sources and types by gender

There were no major differences between males and females when it came to information sources and the types of information preferred. Wantok had higher importance amongst males, whereas for females it was most relevant only for weekly rain, or weekly and daily rain and temperature forecasts (Figures 8.1.10 and 8.1.11).

Males did not seem to find the church a useful source for much SCF information, whilst it was a lot more central and relevant for females (Figures 8.1.10 and 8.1.11). Drought early warning information – the highest ranked information – was perceived by both sexes as being usefully sourced from multiple groups.

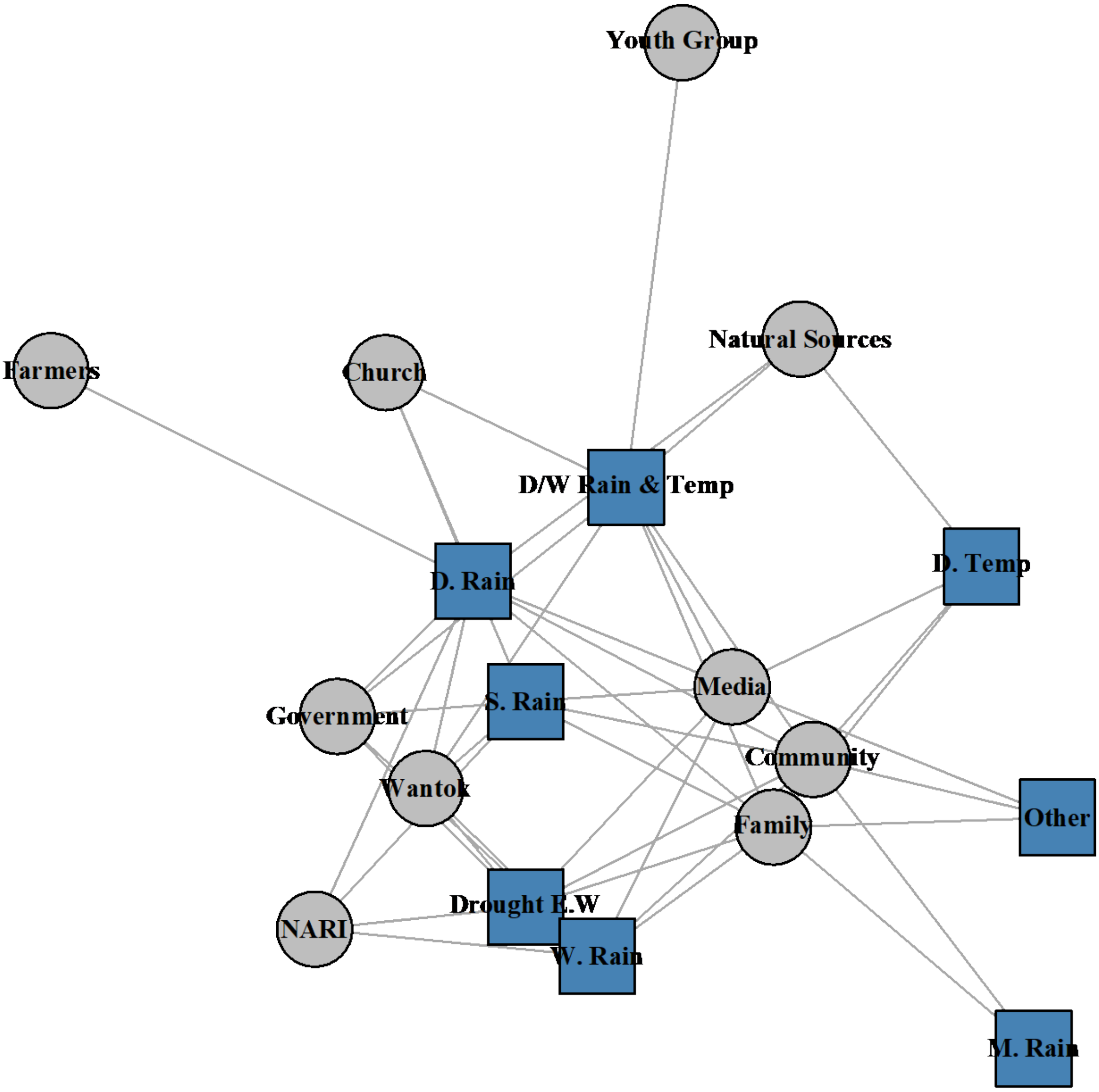

Figure 8.1.10. Male types of information and main sources

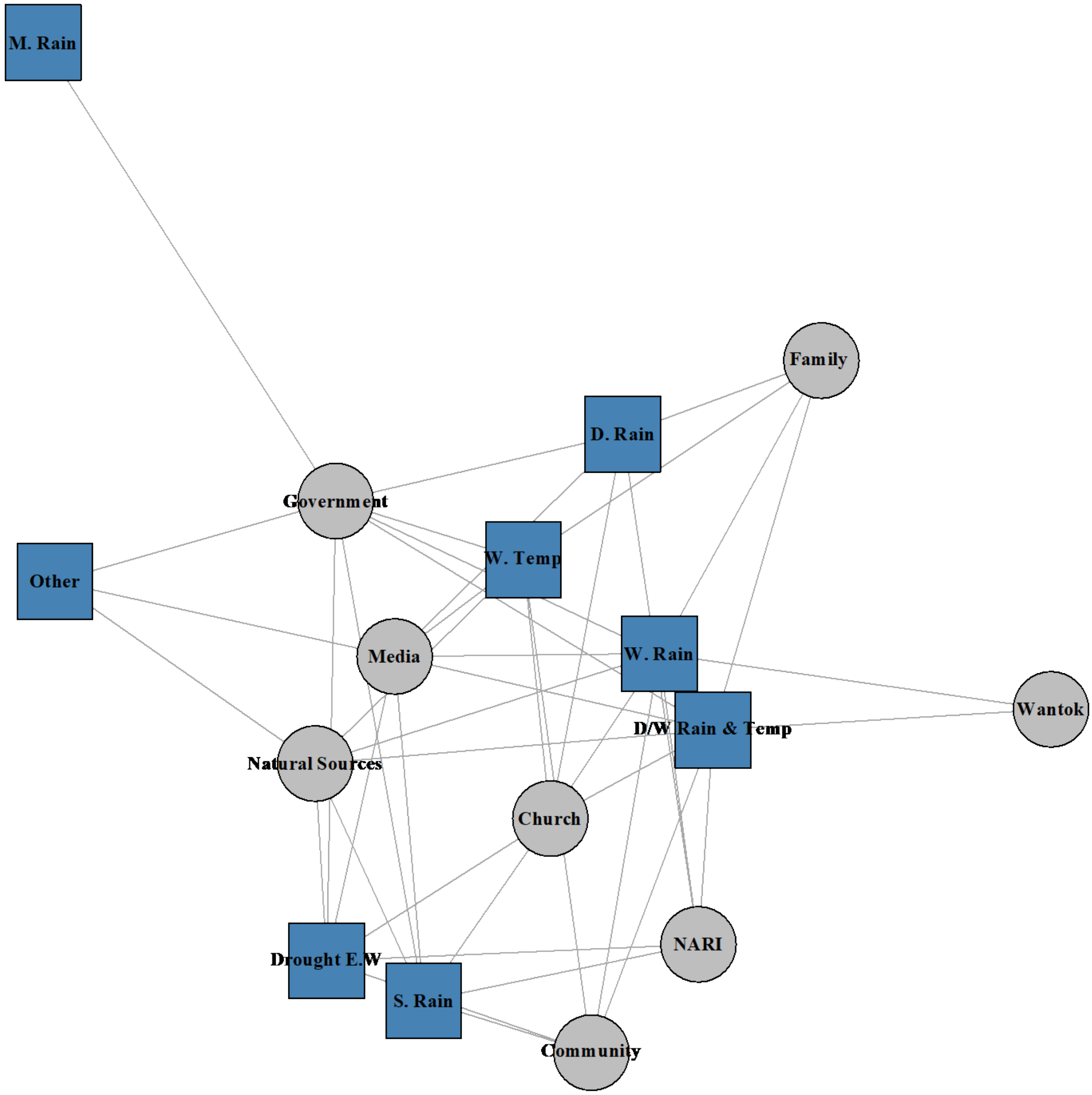

Figure 3. Females' types of information and sources

General observations from gender analysis

There is scope to explore issues of gendered differences/similarities in more depth in future surveys. The small differences between males and females could simply be because when it comes to SCF, both sexes are highly trusting of other groups to exchange information with. Both sexes showed similar patterns for the trust maps, placing family and community as major sources of SCF information.

The SNA shows network behaviour and flow of information, but not adoption of information for farming practices. These maps show that there are few differences between the types of information males or females use or their levels of trust. ***Future surveys should target how knowledge is used.*** This may reveal how SCF information is used in practice by women and men. This may provide insights into the different roles that men and women play in rural landscapes in PNG. Future surveys can help revel how knowledge on SCF is used to inform farming decisions differently between men and women.

Discussion

The findings above show some major themes important for future surveys and disseminating SCF to end users. Across the different maps, it is evident that the ***community/church/family/Wantok individual groups and cliques are important sources of information, and are highly trusted***. All groups were consistently central in all maps, and were avenues to reach smaller community groups, such as farmers or women's groups. This overall behaviour across all villages provides an overview of possible groups to target SCF. If there is to be ***sustained uptake of SCF, then future surveys will need to look at ranking how SCF is used by the different groups. This would enable the research team to link the SCF to farming practices***.

The findings related to Government is interesting. ***Governments are highly trusted, but not central to the network. Government is also a disseminator of knowledge, not a recipient. Without qualitative data, it is difficult to determine if this is actually the case, and if so, why it is. Governments not receiving information from end users (farmers) presents issues of equity in food production.*** If the survey is taken to represent the behaviour of the village, then it is showing that governments are only disseminating information that is relevant to them and to their perceived understanding of what other groups need. This may not align with what the groups genuine information needs are. Key informant interview with key members of the highly trusted groups, and outlier groups, would shed light into confirming the extent to which government responds to different group needs.

Cliques, or sub-networks, were evident throughout the SNA maps. These groups exchange knowledge frequently – however the survey did not show in what social context this information is exchanged. Future studies in this region would benefit from qualitative studies that explore how church, family, and community groups interacts. Given the strong social cohesion provided by groups like the church in rural Pacific contexts, it would be worth exploring the extent to which the church plays the role of a 'boundary organisation' able to disseminate SCF to different groups. In rural development contexts, a boundary organisations brings together different actors from different groups to debate, exchange, and learn about a specific topic of interest to the rural community (Davila *et al.*, 2016).

Farmer-centric findings show that farmers highly trust other groups in their networks across all villages. Previous studies into farmers use of seasonal climate information have shown that social relationships play an important role in building capacity (Saint Ville *et al.*, 2016). ***Given the findings show high levels of trust across a range of groups, knowledge products may not necessarily have to be directly disseminated to farmers.*** Rather, they could be targeted to the number of groups farmers engage with, and these groups form part of the social network of farmers and allows two way information flows. As mentioned earlier, care should be taken when targeting government as disseminators of knowledge, as according to the survey they are unlikely to receive feedback on changing needs of end users.

The maps on types and sources of information present some insights into the dissemination of SCF products. The first relates to the types of information. ***Across all villages, the most important type of information for food production is drought early warning information***. This confirms the need to develop knowledge products that allow end users to understand and plan for unexpected droughts. Given the unknown extent to which seasonal climate forecast information is used to inform decisions in PNG (Cobon et al., 2016), the survey findings show the possible information types that would most benefit end users. ***The second and third most relevant types of information were rainfall and temperature forecasts.*** Although this type of information was found to be important, it was unclear how it would be used and integrated into decision making practices. As such, there needs to be direct linking of technical SCF to possible decision-making options for specific commodities, along with consistent exposure to technical products so end users can become familiar with them (Ziervogel, 2004; Ziervogel and Downing, 2004).

The sources of information were consistent across villages, showing high relevant of family, community, church and Wantok for disseminating SCF information. It is worth noting that there were village specific perceptions on most important sources of information. This should be considered when designing dissemination activities, and villages should be targeted according to the most trusted groups. It is also important to consider consistency of information delivered, to reduce chances of different groups providing conflicting information to groups not central to the network, such as farmers.

There was relatively little difference between genders in the groups they trust and the types of information sought. Both genders trusted the same major central groups (family, community, Wantok, church). The types of info sought was the same, dominantly temperature and rainfall forecasts, however the most important sources varied, with females perceiving official sources, such as government, being less important than immediate family and community sources. An important question for future research is how information is used by different sexes. Given the different roles men and women play in PNG agricultural systems, it is important to understand why different genders want SCF and how they perceive it can influence their on-farm production practices, if at all. Qualitative studies can reveal such differences, and also explore the potential power issues that may emerge if women have more knowledge than men over particular ways of integrating SCF into their practices.

Thinking of long term impact

A series of models exist regarding knowledge transfer from technical SCF outputs to farming communities, and sustaining the use of this technology after project completion. For example, Coelho and Costa (2010), present an end-to-end forecasting system that links initial production of climate forecasts 1 to 6 month in advance, to producing decision making tools that are usable and relevant to specific target groups. End users need to have the capacity to assimilate technical climate information and transfer it to usable strategies for food production. The authors also suggest that monitoring the behavior of the whole end-to-end model is important, to gauge the extent to which the actual transfer and use of information is occurring. A similar adoption model of SCF information is presented by Ziervogel and Downing (2004). This model focused on seasonal forecast dissemination pathways is linear, starting with natural observations, passing through social systems, and ending in an individual's rational choice to use the information provided.

The findings from this SNA broadly align with the SCF adoption models available in the literature, for example see (Gwenzi et al., 2016; Siregar and Crane, 2011; Ziervogel, 2004), the types of forecasts information forms part of the technical observations. The multiple groups in exchanging information and varying levels of trust represent the social processes that convert natural and technical information into contextually usable knowledge. The 'rational choice' aspect of the impact pathway was not clear from the survey. The quantitative nature of surveys do not allow for an exploration of how people make decisions, why they make them, and what influences the choices they make in farming landscapes.

A broad issue to consider when designing projects for ACIAR is the overall focus the agency has on delivering social, economic, and environmental impacts from investments. Providing SCF forecasts to PNG and Pacific communities has the potential of improving practices that integrate SCF information. It will be important to determine the types of commodities being produced in the eastern highlands, and capture baselines on basic economic data at the time of investment. Recording this will provide a way of tracking, long-term, the impact the SCG has had on commodity production.

The SCF products have high potential of delivering salient, credible, and legitimate knowledge to PNG and other countries. These different types of knowledge in specific contexts are important to demonstrate how ACIAR's impact metrics can be embedded in the inception of projects, and monitored through time to determine success pathways for the projects. The SNA maps show potential for strongly capturing legitimacy of knowledge dissemination, given that the findings are providing a snapshot of who how different groups are involved in information dissemination. The salience of SCF is clear – communities unanimously need information to manage drought and use temperature and rainfall information for their farming decisions. The credibility of the technical outputs will depend on the quality of the SCF, however given the institutions involved, it is assumed that this will be high.

Recommendations

The design, conduct, and findings from this SNA present lessons for up-scaling to other countries. Training, conduct, and broader SCF research recommendations are provided below.

Training lessons: use the lessons identified in the Training Report to improve training design, translation, delivery, and contingency plans. See Appendix A for the overview of these training lessons.

Survey conduct lessons:

- Work with key 'champions' in partner agencies in country who demonstrate leadership and can influence others attending training or conducting the survey.
- Move away from paper based surveys towards tablet computer based surveys. This reduces the risk significant delays, as the tablet software can be designed so that data 'errors' are minimised. Data output is also more likely to be consistent. The use of tablets can provide a template for 'rapid' network assessments, so that knowledge based research outputs in can target the most relevant groups.
- The questions need to have more clarity of what community means. This survey showed that there are multiple groups within 'community', which only at an aggregate level present meaningful SNA data.
- Researchers should target end-users of SCF information to identify what their needs and understandings of SCF area, and their role in the social network.
- Design surveys to cater to potential differences in opinion as a result of gendered social relations**.** Such questions can provide more ways of looking at whether men and women use information differently. If it is found that there are differences, there could be important findings for how SCF is targeted and disseminated. Whilst this survey examined differences in gender response, questions were not targeted specifically to either males or females.
- Allow for a major qualitative component that explores why the network behaves the way it does, and why SCF information is needed and how it is used. SNAs present a 'snapshot' of a network, but not the reasons behind it. Qualitative data can reveal how SCF information is expected to be used by different groups, and can help inform the design of dissemination strategies. Qualitative research can also help guide gender analysis and identify differences that may exist.

Broader SCF research and design of impact:

- Design an impact pathway of how technical SCF information will reach end-users, and how this information can be adopted long term.
- Capture as many baselines on commodity production economics, natural resource issues, and the knowledge system of target villages when projects begin. Baselines will allow team monitor evaluate and learn as research findings emerge and are adopted by end users.
- Aim to understand if there is conflicting information on SCF for food production being delivered by end-users (farmers) in order to reduce the level of confusion or misinformation.
- Work with key 'boundary and knowledge brokering' cliques that are highly trusted in the villages to disseminate information. This can enhance legitimacy of knowledge products.

8.2 Seasonal Climate Forecast Review

For the purposes of this review we have focused on tools and services that are provided for seasonal timescales and available for PNG. We examine eighteen tools and operational weather services currently of relevance to PNG which we describe briefly below. There have also been many tools developed over the past decades starting from the 1980's (e.g. Rainman) which incorporated SCF in various ways but most of these are now discontinued, whereas others form the basis of current approaches.

At present the Australian Bureau of Meteorology offers a number of Seasonal Climate Forecast (SCF) products. The most well-known are the Seasonal Outlooks. This suite of knowledge products includes:

- Seasonal Climate Outlooks in Pacific Island Countries (SCOPIC) - SCOPIC was developed to provide Pacific Island nations with an accessible, stand-alone seasonal climate prediction system. The software uses a statistical method to determine forecast probabilities, based on historic data. The software also provides graphics and texts to support the outlooks, including skill tests, hindcasts, data-browsing, statistical analyses, scatter plots, and drought monitoring.
- Predictive Ocean Atmosphere Model for Australia (POAMA) - POAMA outlooks provide forecasts out to nine months ahead. These forecasts include rainfall, temperature, Pacific and Indian Ocean sea-surface temperatures, Madden Julian monitoring and tropical cyclone early warning.
- ENSO wrap-up – regular commentary on the El Niño – Southern Oscillation and temperature conditions in the Pacific Ocean.
- ENSO outlooks - forecast of El Niño and La Niña events using multiple model ensembles - a summary of the opinion of National Climate Centre climatologists on the outputs from eight reputable climate models
- Climate Model Summary - information on Pacific and Indian Ocean sea surface temperatures for the coming 6 months based on a survey of international climate models. It is updated monthly.

NOAA National Prediction Center also offers a seasonal forecast product:

- International Multi-model-Ensemble (NMME) – This provides a forecast 1 to 6 months ahead, comprised of dynamic model forecasts from five major national modeling centers (i.e. NOAA–GFDL, NOAA–NCEP, NASA, NCAR, and the Canadian Meteorological Centre (CMC)). The five models each have a number of runs (ensembles) that are produced to allow the development of a probabilistic forecast. In total the NMME contains 79 ensemble members form the 5 models, all weighted equally. The forecast is a tercile based forecast of rainfall or temperature.

IRI probabilistic seasonal climate forecast product is based on:

- A re-calibration of model output from the U.S. National Oceanographic and Atmospheric Administration (NOAA)'s North American Multi-Model Ensemble Project (NMME). This includes ensemble seasonal prediction systems of NOAA's National Centers for Environmental Prediction, Environment and Climate Change Canada, NOAA/Geophysical Fluid Dynamics Laboratory, NASA, NCAR and COLA/University of Miami. The output from each NMME model is re-calibrated prior to multi-model ensembling to form reliable probability forecasts. The forecasts are now presented on a 1-degree latitude-longitude grid. The SCF for the Australian region includes PNG.

APEC Climate Centre has three forecast products that are relevant for PNG. These are:

- APCC Multi-model Ensemble Probabilistic or Deterministic forecast (MME) – This forecast product like the others discussed above includes ensemble seasonal prediction systems from a total of 17 international climate research agencies. APCC issues monthly rolling global predictions of temperature and precipitation for the upcoming 3 month period. These forecasts utilize deterministic (based on ensemble mean) and probabilistic (based on the full set of ensemble members) interpretation of the well-validated multi-model ensemble (MME) seasonal prediction system. Currently, 17 prominent operational climate centres and research institutes from nine APEC member economies participate in the APCC operational MME prediction by routinely providing their predictions in the form of ensembles of global forecast fields.

- APCC Climate Information Tool Kit (CLIK1.0) - This tool was developed to help users to maximize the use of climate information and forecasts. The CLIK system provides customized multi-model ensemble (MME) prediction with verification. It also has a statistical downscaling tool which conducts predictor variable pre-screening, basic diagnostic testing, and graphing of climate data from January 2008 onwards.
- APCC Global Drought and Flood monitoring - The APCC Global Drought Monitoring is based on the Standardized Precipitation Index and is available in the form of maps for the last 1-month, 3-month, 6-month and 12-month periods using monthly precipitation at 2.5°x2.5° resolution. SPI between -1.0 to -1.49 indicates moderate drought, -1.5 to -2.0 severe drought, and less than -2.0 extreme drought conditions.

The Japanese Meteorological Agency (JMA) produces a global forecast product:

- The forecast product is a multi-model ensemble (JMA MME) - JMA operates the ensemble prediction system of an atmospheric global circulation model (AGCM) for one-month prediction and atmosphere-ocean coupled global circulation model (CGCM) for three-month and warm/cold season prediction. Ensemble prediction products, verification charts and description of the ensemble prediction system are available, although this is via a user pay model.

The UK Hadley centre produces a single global seasonal forecast product that could be relevant to PNG. This product is as follows:

- The Global seasonal forecasting system (GloSea5) forecasting system is based on the output from forecasts made using a coupled ocean-atmosphere General Circulation Model (GCM). This is a version of the Met Office climate prediction model: HadGEM3 family climate model, which uses the UM (Met Office Unified Model) atmosphere, NEMO (Nucleus for European Modelling of the Ocean) ocean and MOSES (Met Office Surface Exchange Scheme) land surface. GloSea5 uses the N216 version (0.8 degrees in latitude and 0.5 degrees in longitude, which is approx. 50 km in mid-latitudes, in the horizontal) for the atmosphere, and the ORCA0.25 grid (0.25 degrees) for the ocean. Each day forecasts are started from observed conditions corresponding to that day, to create a 2-member 'perturbed physics' ensemble: the different ensemble members are created by randomly perturbing parameters in physical parametrisations. By pooling three weeks' perturbed-physics ensembles together, a larger, lagged-start ensemble is created, which samples both initial-condition and model uncertainties.

The European Centre for Medium range Weather Forecasting has also developed a multi-model ensemble forecast product. This global forecast product is as follows:

- The EUROSIP multi-model system from ECMWF produces a number of multi-model products which are created from the integrated output of the five major European climate models. These multi-model products include 1 to 6 month temperature and rainfall forecasts that can be accessed via the ECMWF website.

Review of the current use of SCF

The current approaches used for producing seasonal climate forecasts include the use of physically based dynamical global climate models (Anderson et al., 2007; Cane, et al., 1994; Saha et al., 2006), regional climate models (Chou, et al., 2005; Reis, et al., 2007; Sun, et al., 2005, 2006), empirically based statistical models (Wu, et al., 2009; Hastenrath, et al., 2009), or a combination of dynamical and empirical models (Coelho, 2010). All these four approaches produce probabilistic forecasts for expressing the existing uncertainties in the forecasting process.

Coelho (2010) presented a stylised model for an end-to-end forecasting system. At the top end of this framework is the climate science, in charge of producing climate forecasts through knowledge of climate processes (Figure 8.2.1). This in turn feeds the so-called systems science, placed at the centre of the framework (Figure 8.2.1). Systems science investigates impacts of climate on natural and human systems through knowledge about physical and socio-economic processes and impacts and in the case of agriculture this would include biophysical models at crop and farm scale (Figure 8.2.1). The systems science is capable of analysing climate risk in conjunction with non-climate related risks (Coelho 2010).

At the bottom end of the framework, decision making is performed on the basis of forecast information jointly produced by climate and systems sciences (Figure 8.2.1). Such a framework allows usefulness/utility assessment of climate forecast information through the use of application models predicting variables of societal interest (e.g. crop yield, risk of soil degradation etc.). This assessment is distinct from the traditional climate forecast assessment generally performed in climate science, which directly compares observed climate with forecast climate produced by climate models. By assessing the output at the bottom end of this framework the complete end-to-end forecasting system is indirectly assessed.

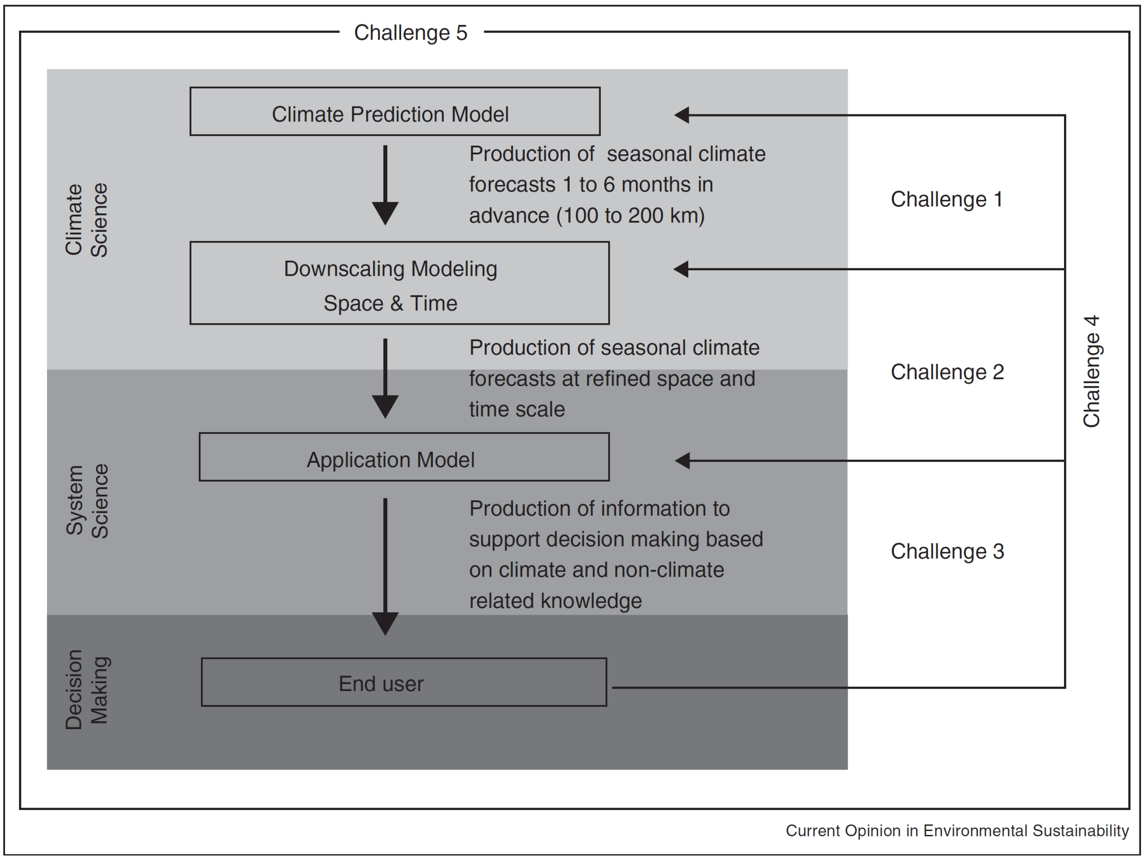

Figure 8.2.1. A stylised version of the end-to-end forecasting system (after Coelho, 2010)

The link between each component of the illustrated 'end-to-end' system represents a challenge for the system success in terms of forecast information production relevant for user applications. The success of integrating seasonal climate forecasts in user applications will therefore only be achieved if the entire chain of challenges is thoroughly resolved (Ash et al., 2007; Coehlo and Costa, 2010; Hansen 2001; Siregar et al., 2011; Vaughan and Dessai, 2014; Shafiee-Jood et al., 2014). The first challenge appears within climate science and focusses on the production of climate forecast information of relevant variables for user applications (Roncoli et al., 2009) one to six months in advance. This challenge is addressed with the aid of physically based global climate models (GCMs – Hudson et al., 2013), empirically/statistically based models (Kokic et al., 2011; Hastenrath et al., 2009] or a combination of both (Coelho et al., 2006). However, these models generally produce forecast information at coarse spatial resolution (of the order of 100–200km), of variable lead-times and variable accuracy.

As application models usually require climate forecast information at much refined spatial and time resolution, there is often an interest in downscaling the forecasts produced by climate models to spatial scale in which application models are run (e.g. field scale). Such refinement of forecast information represents the second challenge that is placed in the interface between climate and systems science. Attempts to address this challenge are undertaken via simple scaling of site based daily climate information, the development of heuristics that can be informed by broad scale SCF information or creating statistical relationships with local scale derived variables such as yield or plant available water. However these approaches inevitably promote the propagation of systematic biases from the SCF resolution to the local scale where application models usually operates (Coelho and Costa, 2010).

The third challenge involves the limitations of the application model that the SCF information is being coupled to. The applications models are usually either process-based (e.g. APSIM, Yield Prophet, GrassGROW etc.) or empirically based (e.g. FlowerCalc, "How Wet"). The recent literature contains a number of examples of the use of application models producing relevant information for decision making in agriculture. This will be discussed in later sections of this review.

At the bottom end of the framework is the end user who will receive the produced information (e.g. crop yield forecast, stream flow forecast and nitrogen management advice) and combine with other non-climate related information to make decisions. This process can be either informally achieved through the farmer planning or formally undertaken using additional planning or decision support tools. Effective communication between climate and system scientists with decision makers is a fundamental ingredient for successfully resolving the third challenge (Ash et al., 2009, Hayman et al., 2007; Roncoli et al., 2009). End users need to be trained for assimilating the information produced by climate and system scientists to maximize the utility of the forecasts in their decisions (Coelho and Costa, 2010). For example, application models can produce probabilistic forecast information based on ensemble of climate model forecasts, and end users need to be prepared for using this information. In the PNG context this remains a very challenging undertaking given numeracy and literacy limitations as well as access to agronomic extension staff.

The fourth challenge is to stimulate feedback provision by the end user to system and climate scientists for improving the forecasting process (Crean et al., 2015; Hayman et al., 2007; Marshall et al., 1996). Such feedback is of great importance for tailoring forecast information adequately to facilitate decision making. Importantly, many farmers say that they do not need climate forecasts at finer and finer spatial scales unless this actually brings greater reliability (Dunn et al., 2015). Rather, they often express an interest in robust, regional-scale forecasts. Hence, the specific systems framework above needs to be recognised as context dependent – for some farmers/applications it may work whereas for others it may not add value or fit into their decision-making processes. It is acknowledged that end user engagement is a critical step in ensuring that existing products and services can be enhanced and new relevant information developed.

Finally, the fifth and fundamental challenge for the success of an end-to-end forecasting system able to effectively integrate seasonal climate forecasts in users' applications is to design and implement the whole system. Coelho and Costa (2010) suggest this to be the most difficult challenge involving trans-disciplinary work among climate scientists, system scientists and decision makers (who often have the greatest knowledge of the whole system). Others might argue that the greatest challenge is to make sure that the forecasts benefit the people who need them most, rather than the ones who are already economically advantaged as this can result in further separation of adaptive capacity. The involvement of users is these projects is fundamental for improving credibility and utility of forecast applications.

There is a clear need for additional inter-disciplinary research to facilitate more effective framing and implementation of end-to-end forecasting systems able to objectively use seasonal forecast information in user-oriented applications. In Australia, a number of case study examples have been identified that provide insights into the challenges of incorporating SCF information into application models (addressed below). For the purposes of this review we have separated the case studies into those related to on-farm applications, those relating to agricultural marketing decisions and those supporting policy decisions.

Knowledge gaps and potential for expanding and updating/improving the range of tools available to PNG

This literature review highlights a number of ongoing knowledge gaps and improvements that could be made to improve SCF uptake and the range of knowledge products that incorporate seasonal climate conditions. This review and results from the surveys undertaken in this study highlight that both farmers and R&D staff are familiar with the historic climate variability of their region and where to source weather and climate information from, but are less knowledgeable with regards to the drivers of climate variability, the level of regional and temporal SCF skill/accuracy and how the SCF could potentially be used to improve farm profitability, value chain management or policy development and implementation. The review and survey revealed that the most significant barriers to use of SCF remain:

- perceived lack of local or regional relevance;
- perceived lack of sufficient lead time;
- perceived lack of skill/accuracy during periods when critical farm level decisions and period of time during which the SCF has perceived skill;
- context relevant knowledge products;
- Lack of formal training or capacity building, and
- perceived lack of application to understanding how SCF's translate to measurable improvements in farm profitability.

In recent years dynamically-based atmospheric general circulation models (AGCMs) have become a mainstream tool in seasonal climate forecasting, with a de-emphasis on existing statistical forecast systems. This is largely due to perceived limitations in performance of statistical systems in capturing the changing teleconnections in response to anthropogenic climate change.

Over the last five years, few formal statistical versus dynamic forecast inter-comparisons have been made and even fewer still have examined the economic outcomes of using either forecasting approach to direct/support on-farm management decisions. The research to date (summarised above) has shown that the value of modifying specific management decisions in response to existing forecasts is dependent very much on existing risk management baseline, location, soils and type of enterprise. Benefits of between $1 and $66 per hectare have been demonstrated across a number of independent modelling experiments in Australia (See Reference section below). With no experiments of this type documented in PNG.

Despite the large number of studies undertaken in Australia, these results are difficult to compare given different locations, starting conditions, modelling frameworks and management decisions analysed and so ***one key recommendation from this review is that a standardised approach to evaluating the economic returns should be attempted in PNG***. This would allow improved inter-comparisons of different SCFs (dynamic, statistical and hybrid) as well as allowing the development of a database of economic evaluation across multiple locations and enterprises.

As part of this common evaluation approach, ***there should be some efforts made to agree on a single measure of economic performance for PNG***. At a minimum the metric should represent the whole-farm and should incorporate both input cost and output profit and some estimate of risk. Of growing acceptance in the climate change adaptation research field, is the "Value at Risk" (VaR) metric. In financial mathematics and financial risk management, VaR is a widely used risk measure of the risk of loss of a specific portfolio of financial exposures. For climate change adaptation studies (Bell et al., 2014; Fuss et al., 2012; Leblois and Quirion, 2010, Strauss et al., 2010; etc.), the effectiveness of the adaptation option is measured according to the risk of farm profitability being negative in 20% of years. Similar application of this or a similar integrative economic metric could be made for SCF evaluations in order to convey both profitability and risk.

A number of review papers (White et al., 2013, 2015) have also identified the importance of ***developing multi-week prediction*** in addition to the seasonal forecasts.

To-date the limited inter-comparison of existing SCFs has revealed that different models provide different levels of skill/accuracy for different lead-times and regions. The difficulty of communicating this in simple, balanced ways has had a significant constraining impact on the uptake of the existing forecasts given the high rainfall variability and marked seasonality of rainfall in Australia. There can be institutional and structural reasons for this mismatch between the research that is needed and that which is done (Lacey et al. 2015) and this needs to be addressed by leadership within both the user and researcher communities. Without this enhanced level of inter-comparison producers will be left with sometimes conflicting results from different SCF's without being able to determine which has more relevance for their region or season.

More effective integration of climate and statistical sciences are required to produce skilful forecasts on seasonal and sub-seasonal timescales and thus allow the tailoring of climate information to specific user needs and for creating opportunities to improve climate risk management. Modern statistical methods allow the output of multiple dynamic models as well as statistical models to be integrated into a much more powerful forecast that can potentially address the limitation addressed in the above paragraph (Wang et al., 2013).

At present no approaches have been used in PNG to bring together information from a range of seasonal climate forecasting tools. Internationally attempts are being made develop "consensus forecasts" and have used simple equal weighting scheme to aggregate data into a single forecast. The approach we recommend includes the introduction of a skill based weighting scheme that would vary across seasons based on model performance.

In response to the above existing knowledge/capacity gaps, we recommend the ***development of an integrated seasonal climate forecasting system that incorporates existing SCF information as well as other key climate drivers*** from both the Indian Pacific and southern oceans and other key climate drivers expressed via global teleconnections using a combination of a mixed effect state-space statistical modelling approach and spatio-temporal statistical methods.

In addition to improved multi-model integration, the ***production of more localised or regionalised forecasts are required*** in order to overcome the perceived lack of local relevance (e.g. Dunn et al. 2015). As part of the survey undertaken for this project, participants were asked about barriers to current forecast use. 76% of the respondents indicated that lack of local or regional relevance was a barrier to adoption. As part of the survey, participants were asked to identify scales at which the information would be deemed appropriate. 32% of participants indicated that information at village scale would be appropriate. ***For this reason only two of the SCF products listed above are relevant for further application in PNG. The first is SCOPIC developed by the Australian Bureau of Meteorology and produced by the PNG NWS and the second is the APCC Climate Information Tool Kit (CLIK1.0). Both forecast products are capable of being regionalised using statistical downscaling methods. The SCOPIC forecast product, if more extensively applied to local regions might represent the preferred forecast product given its ease of use and the familiarity of the PNG NWS with this product. The downside of this approach is that it is not a multi-model ensemble approach and so the prospects of improving the SCF skill are limited.***

The probabilistic nature of seasonal forecasts remains as one of the on-going barriers to clear communication (Taylor et al., 2015; White et al., 2015). It is likely that many farmers simply react to a headline warning of an El Niño as having a certain impact at their location (i.e. a deterministic forecast). This ignores the probability basis as determined by the complexity of past seasonal and spatial patterns (Taylor et al., 2015; White et al., 2015). In an attempt to over-come this barrier, ***additional knowledge products are required that allow the user to more effectively translate the probabilities to a self-selected format/presentation they are more familiar with***. These could include:

- Probability of a yield threshold;
- Estimates of threshold soil moisture;
- Estimates of likely in-crop rainfall etc.

To be useful and valuable to commercial growers in PNG, ***climate forecasting must address not just individually-relevant problems at farm or policy level, but must take a 'whole industry' perspective to ensure that benefits achieved at one level are not undone at the next*** (Lim-Camacho et al., 2015; Meinke, 2006). This can be achieved via an examination of how SCF information can be integrated across the whole value chain.

An examination of this approach was undertaken for the Australian sugar industry (Everingham et al., 2002). Australian sugarcane industries operate across an integrated value chain comprising cane growing, harvesting, transport, milling, marketing and shipping. Sugarcane industries world-wide are exposed to uncertain and highly variable climatic conditions, which have large impacts across the commodity sectors. The integration of a SCF into industry decision-making was shown to provide enhanced profitability and international competitiveness.

The application was applied to the derivation of information to support decisions relating to yield forecasting, harvest management, and the use of irrigation. Whilst this work was only evaluated economically for a number of case study farms, the current high adoption rates of SCF within the sugar industry would suggest a positive and strong return on investment. This is supported by Antony et al. (2002) who analysed the value of climate forecasting to management systems in just one sugar milling region in Australia. They determined that in one case study season (austral winter, 1998) the value of a probabilistic climate forecasting system amounted to approximately AUD $1.9m for one relatively small cane growing region. The assessment was made incorporating decisions at both the farm and mill scale. However, they point out that if prior 'perfect knowledge' of all daily rainfall patterns for that season had been possible when key decisions were being made, the value to industry would have amounted to AUD $20m, ten times the value currently achievable through existing climate forecasting technology.

8.3 Weather Stations

Three Davis Vantage Pro 2 weather station were purchased from Instrument Choice in Melbourne and shipped to PNG for Installation. The Vantage Pro 2 stations were selected as they are able to transmit weather information by wireless signal to the digital display up to 300 meters away (line of sight, typical range through walls is 60 to 120m).

The weather stations track several local weather variables, including temperature, humidity, wind speed/direction, solar radiation and rainfall totals. It stores this data on a USB enabled logger which can be accessed using the WeatherLinkIP software and data cable. The sensor suite uses solar power to run all the loggers with a backup battery supply included. All of the sensor's electronic components are housed inside of a weather-resistant shelter and have been tested in harsh tropical conditions. The Vantage Pro2 comes with the outdoor temperature/humidity sensor, an anemometer with 12m cable, rainfall sensor and it also comes with a radiation shield to protect the sensor suite. The digital display allows users, or in this case village communities to see how the weather conditions are unfolding and also to gain a 48hr weather forecast based on internal calculations made by the software.

Prior to the installation of the weather stations NARI staff from Aiyura undertook community engagement activities at each of the three villages. During this activity the community were engaged in a conversation regarding the value of seasonal climate information for farming and other decisions and were also informed about the ability of the weather stations to provide a 48hr forecast of weather. During the engagement three community custodians were identified who were provided access to the digital display and shown how to produce a 48hr forecast. The custodians included:

- Mrs. Kusha, Headmistress, Ontobura Primary School;
- Mr. Joseph Giul, Okapa District DRDO at Okapa; and
- Mr. George Mosinokawe, YYNWA Advisor at Ifiyufa.

Historical weather data has been collected for the period 11/05/2017 to 21/10/2017 for two of the locations (Okapa and Ifiyufa) with some technical problems with the Ontobura weather stations data till 06/06/2017 is available. Efforts to rectify the problem have been undertaken but will require replacement of the logger. This will be undertaken during the next phase of this project.

An example of the data collected from the weather stations can be seen in Table 8.3.1. The measured variables collected include:

- Temperature
- Rainfall
- Pressure
- Solar radiation
- UV
- Wind speed and direction

A series of derived variables are also collected. These include:

- Dewpoint temperature - the temperature to which air must be cooled for saturation (100% relative humidity) to occur, providing there is no change in water content
- THW Index - uses humidity, temperature and wind to calculate an apparent temperature that incorporates the cooling effects of wind on our perception of temperature.

The ongoing collection and processing of this data will be undertaken by NARI using funds from this project as well as ongoing funds from other research projects in the area. We have engaged with the PNG NWS and they were present at the establishment of the weather station in Ifiyufa. They have been provided with a copy of the data management software and the weather station data has been shared with them.

The data received to-date has been graphed and examples have been included in this report (i.e. Figures 8.3.1 to Figure 8.3.3). This includes temperature, rainfall and UV time series data for each site.

One of the research activities was to develop software to analyse and measure trends in daily weather data. Initially we were going to use the data from the weather stations to test the software but due to the short records at each site we used other weather records provided by the PNG NWS. A full description of the variables we can now calculate is contained in Section 8.4. The individual station records for both Goroka and Port Moresby are presented in this report (i.e. Figure 8.3.4 to 8.3.7).

Table 8.3.1 A Table containing the weather data recorded by the Okapa weather station for the period 11/05/2017 to 11/06/2017.

OKAPA												
Year	Month	Day	Average of Temp	Average of Humidity	Average of DEW Point	Average of WIND Speed	Average of THW Index	Average of Pressure	Sum of Rain	Max of UV Index	Max of Hi Temp	Min of Low Temp
			°C	%	°C	$m.s^{-1}$	°C	hPa	mm	MEDs	°C	°C
2017	5	11	21.2	78.6	17.1	0.6	21.8	1007.7	7.8	9.8	26.1	17.6
2017	5	12	19.8	81.1	16.3	0.2	20.3	1009.5	0.0	6.5	27.5	16.8
2017	5	13	19.3	83.6	16.2	0.0	19.8	1009.4	1.6	9.4	27.4	14.9
2017	5	14	19.6	83.8	16.6	0.1	20.1	1009.4	0.2	8.4	25.4	15.7
2017	5	15	20.3	81.4	16.8	0.4	20.9	1009.4	0.4	8.7	26.8	16.6
2017	5	16	19.2	84.2	16.3	0.4	19.7	1010.3	7.6	8.5	25.7	15.1
2017	5	17	19.6	79.9	15.7	0.7	20.0	1011.1	0.0	10.2	27.1	13.8
2017	5	18	19.9	79.0	15.8	0.5	20.3	1009.9	0.0	9.7	28.2	13.6
2017	5	19	19.3	86.4	16.8	0.3	19.9	1009.0	27.6	6.1	26.1	16.1
2017	5	20	20.3	84.1	17.3	0.3	21.0	1008.8	0.0	9.9	26.7	16.4
2017	5	21	20.9	81.3	17.3	0.5	21.6	1009.1	0.8	8.8	28.5	17.4
2017	5	22	19.0	88.0	16.9	0.3	19.6	1009.9	3.0	7.7	24.6	15.7
2017	5	23	19.4	83.3	16.3	0.6	19.9	1010.7	2.0	8.9	26.5	14.2
2017	5	24	20.1	79.9	16.3	0.7	20.6	1009.8	0.0	8.9	26.6	16.8
2017	5	25	19.7	81.0	16.0	0.9	20.1	1009.6	0.0	9.7	25.6	15.2
2017	5	26	19.1	85.5	16.5	0.5	19.7	1010.4	0.6	7.2	25.2	15.2
2017	5	27	18.9	84.7	16.1	0.4	19.4	1010.8	0.0	9.0	26.3	13.4
2017	5	28	19.4	83.1	16.3	0.3	19.9	1010.9	0.8	7.4	24.5	15.7
2017	5	29	19.1	81.7	15.7	0.4	19.5	1011.5	0.0	7.6	26.3	12.7
2017	5	30	19.5	83.2	16.5	0.2	20.1	1011.1	0.2	7.1	25.6	15.7
2017	5	31	19.3	82.8	16.0	0.6	19.7	1011.1	0.0	9.4	25.8	16.1
2017	6	1	19.4	79.2	15.4	0.6	19.8	1011.4	0.0	9.0	27.4	13.8
2017	6	2	20.2	80.0	16.3	0.5	20.7	1010.5	1.4	8.1	28.2	16.3
2017	6	3	19.6	84.7	16.7	0.4	20.1	1009.7	3.2	8.2	26.3	16.2
2017	6	4	18.7	86.4	16.2	0.4	19.2	1010.2	0.0	7.9	25.2	15.0
2017	6	5	19.9	83.5	16.7	0.3	20.4	1010.9	0.2	8.5	27.3	15.9
2017	6	6	19.3	87.4	17.0	0.3	19.9	1011.0	2.8	9.0	25.8	15.8
2017	6	7	18.7	86.0	16.1	0.3	19.1	1012.0	1.6	6.1	23.8	15.4
2017	6	8	18.7	86.1	16.1	0.3	19.1	1012.8	0.0	7.0	25.7	15.6
2017	6	9	16.8	78.3	12.7	0.6	17.0	1013.9	0.0	6.8	25.7	11.0
2017	6	10	17.6	76.0	16.2	0.3	18.0	1012.0	0.0	2.7	21.2	15.6
2017	6	11	18.5	78.0	16.0	0.2	18.8	1012.6	0.0	8.4	25.3	12.0

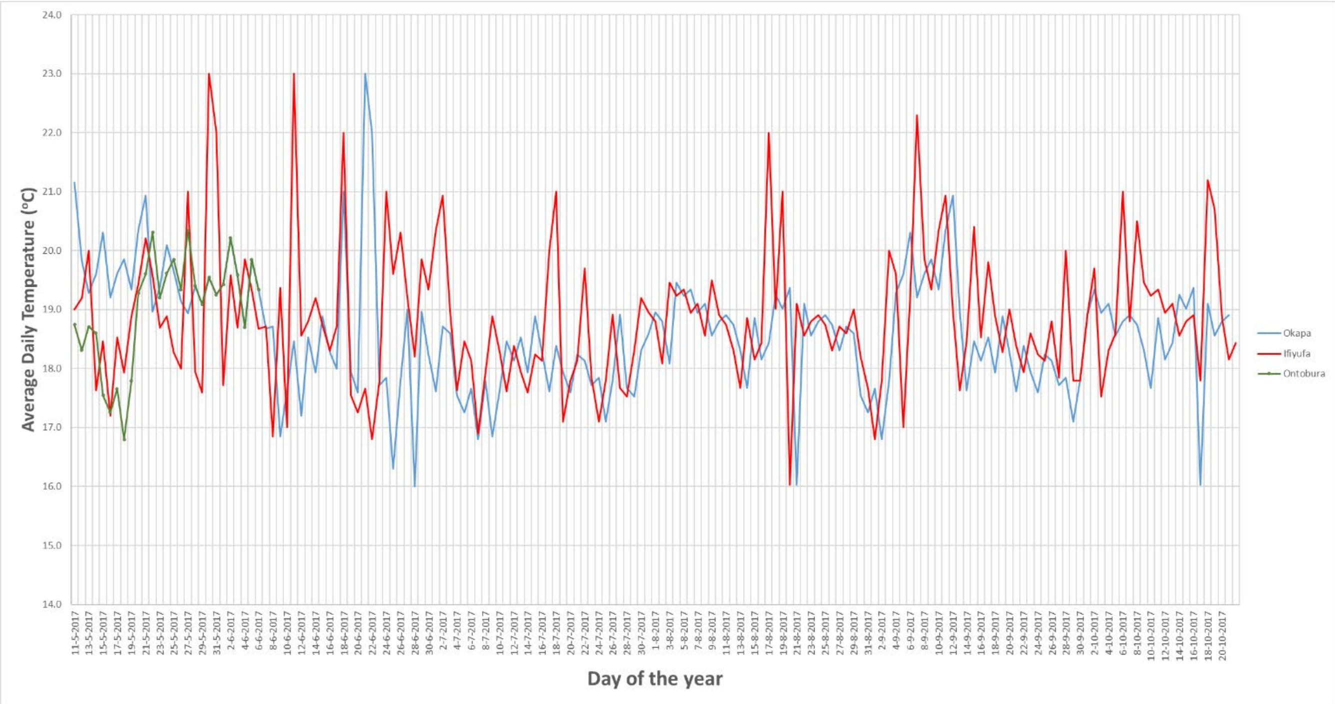

Figure 8.3.1. A time series of average daily temperatures for each of the three sites.

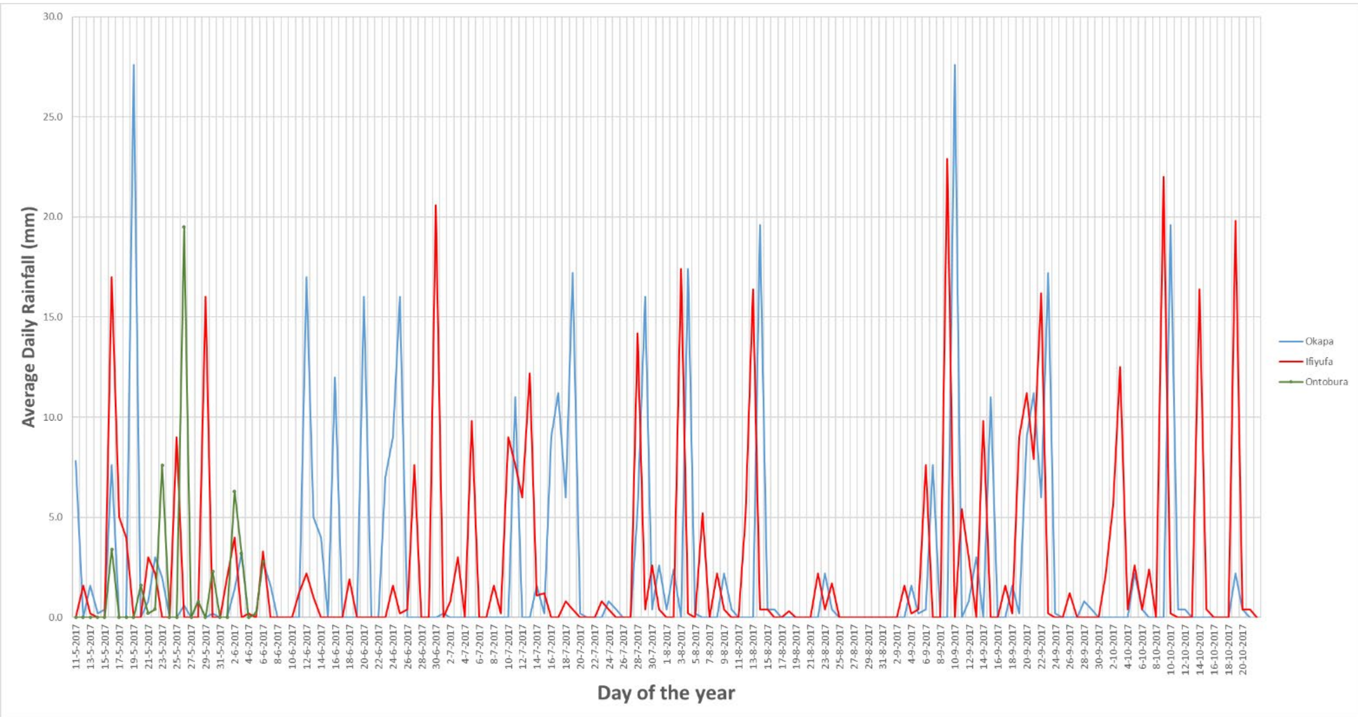

Figure 8.3.2. A time series of average daily rainfall for each of the three sites.

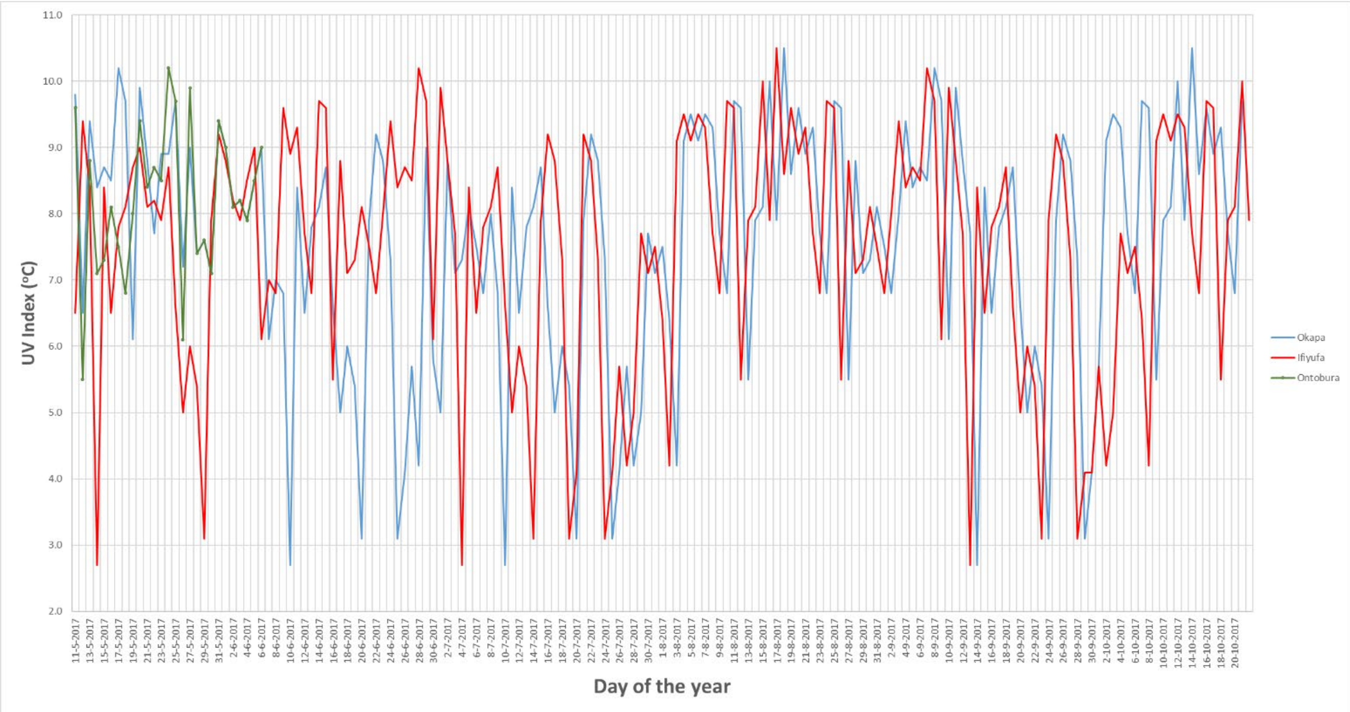

Figure 8.3.3. A time series of average daily UV for each of the three sites.

The trend analysis software was developed in R which is a programming language and environment for statistical computing and graphics. It is a GNU project which is similar to the S language and environment which was developed at Bell Laboratories (formerly AT&T, now Lucent Technologies) by John Chambers and colleagues. R is free software that has been developed to run on a range of different platforms.

R provides a wide variety of statistical (linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, etc.) and graphical techniques, and is highly extensible.

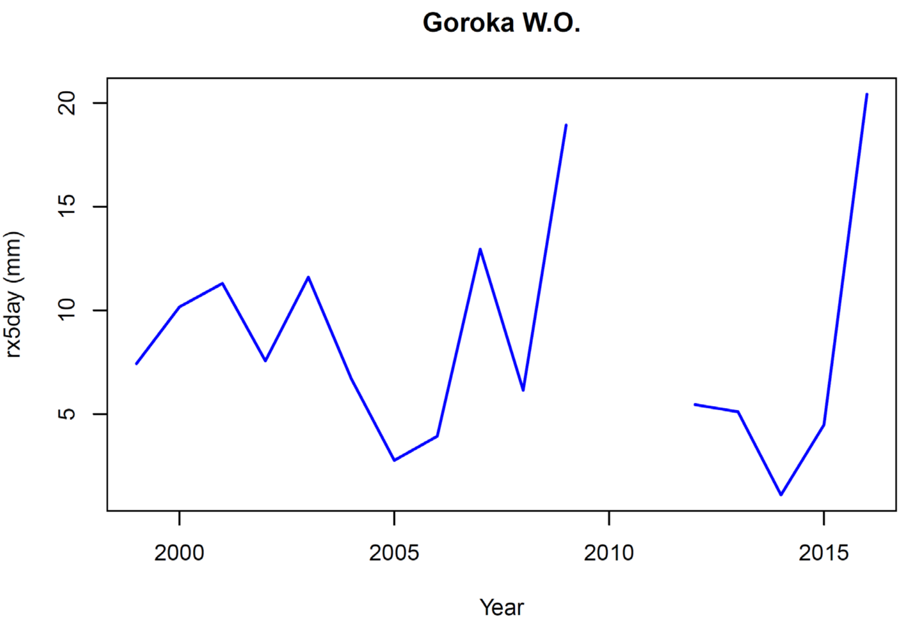

Figure 8.3.4. A time series of the maximum consecutive 5-day precipitation amount for the Goroka NWS weather station.

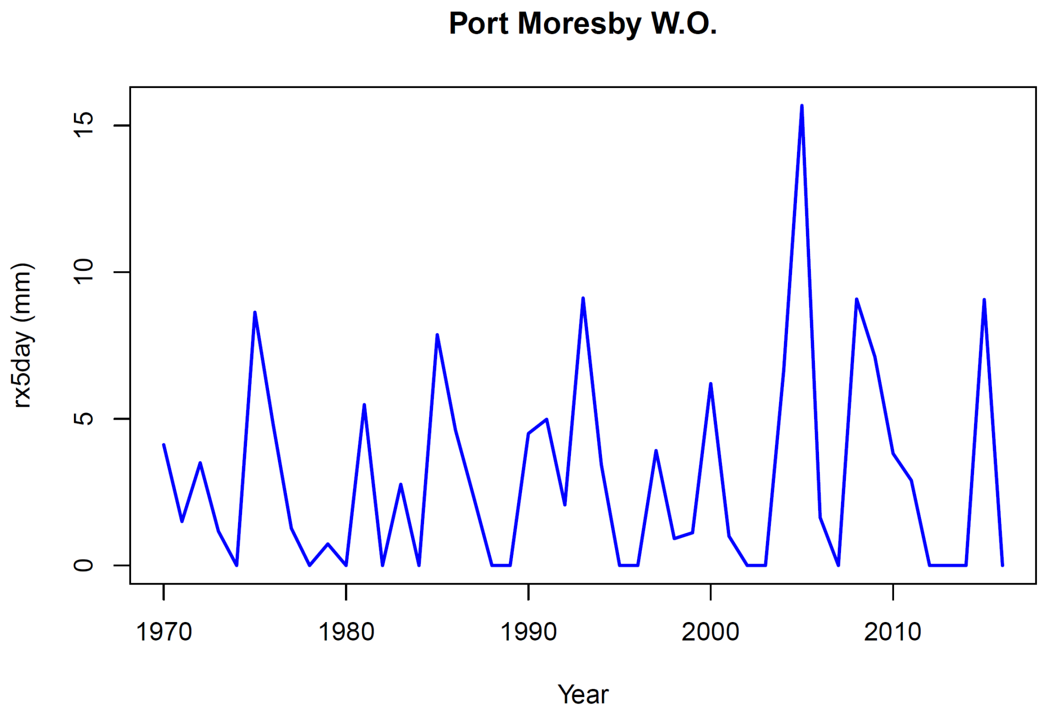

Figure 8.3.5. A time series of the maximum consecutive 5-day precipitation amount for the Port Moresby NWS weather station.

Figure 8.3.4 and Figure 8.3.5 depict the maximum consecutive 5-day precipitation amount for the length of the weather stations operation. The Goroka data is much more limited in extent and has considerable missing data. The Port Moresby site is much more extensive and does show some slight increase in the amount of precipitation falling during these consecutive rainfall events.

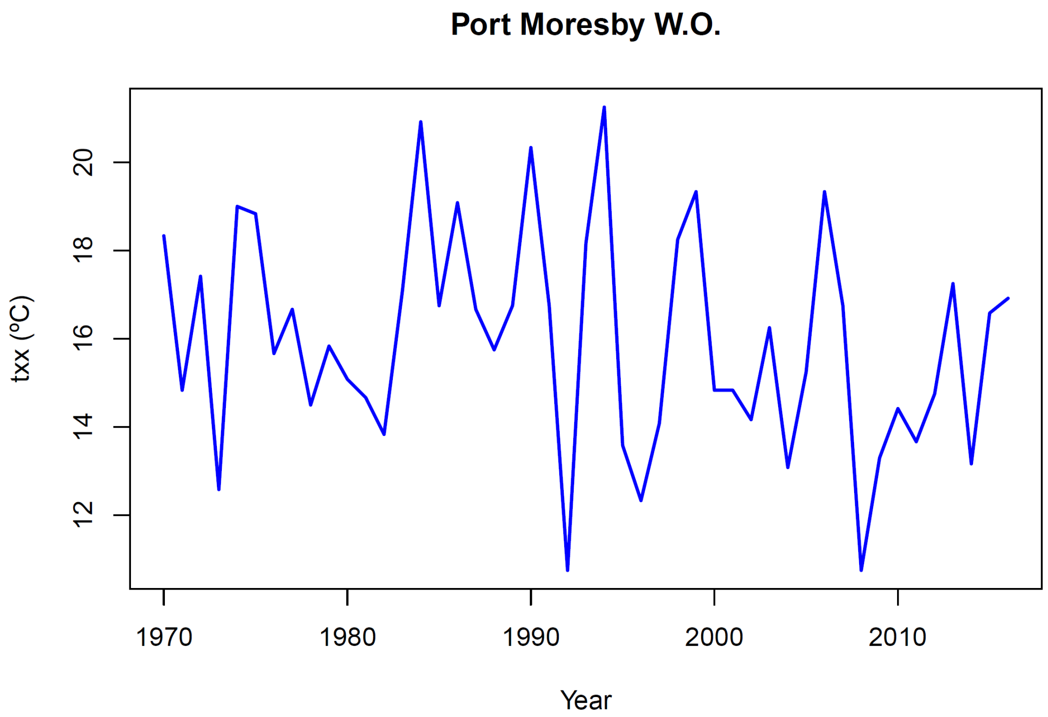

Figure 8.3.6. A time series of the annual maximum value of daily maximum temperature for the Port Moresby NWS weather station.

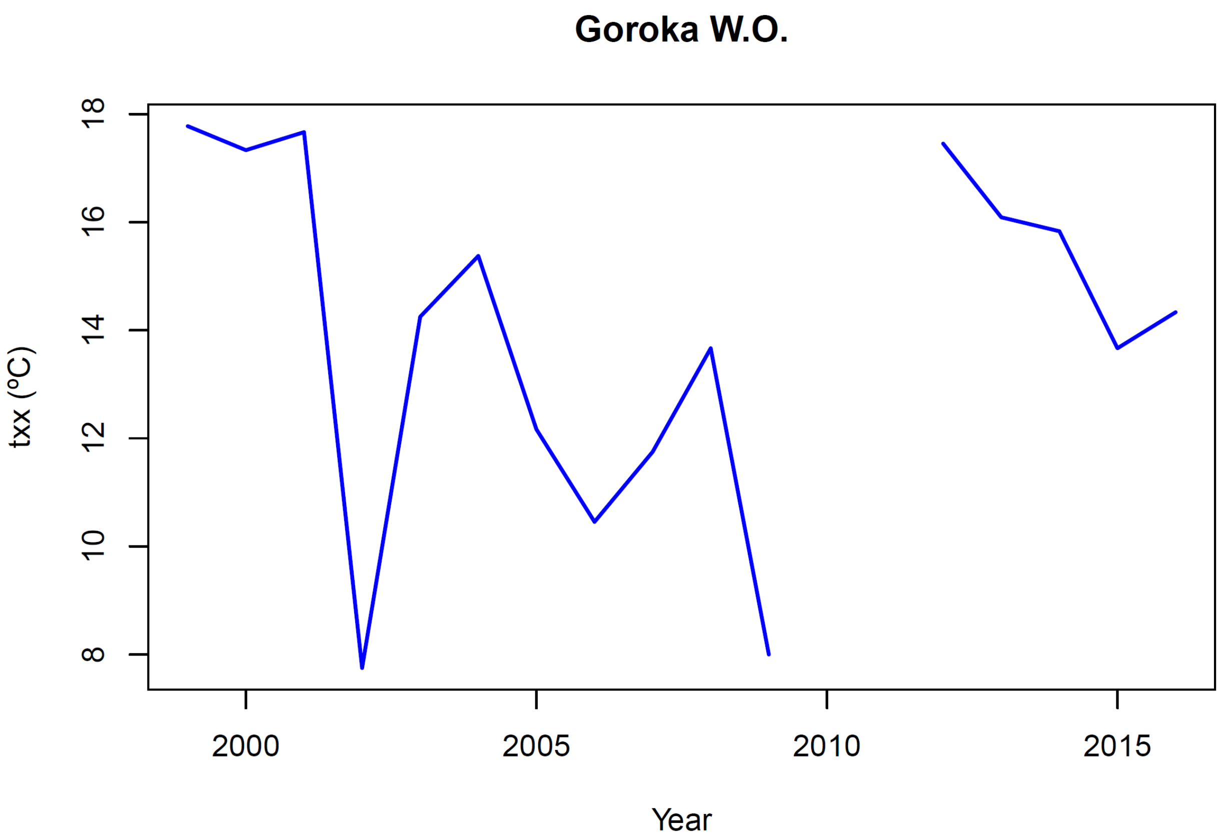

Figure 8.3.7. A time series of the annual maximum value of daily maximum temperature for the Goroka NWS weather station.

Figure 8.3.6 and Figure 8.3.7 depict the maximum value of the daily maximum temperature for both Port Moresby and Goroka the limited data for Goroka is problematic for further trend analysis and precipitated the use of complex statistical modelling described in section 8.4.

8.4 Climate Trend mapping

Communities in the Pacific Island countries reliant on agriculture-based livelihood systems have been identified as particularly at risk from climate variability and climate change. The implications of a changing climate are likely increases in crop failure, new patterns of pests and diseases, lack of appropriate seed and plant material, and potential loss of arable land. Hence, to understand how agricultural vulnerability has changed in PNG it is proposed to produce maps of changes in historical rainfall and temperature variability through a set of tailored climate indices.

Data considered for the analysis are a combination of point based data from weather stations in PNG and gridded climate information from the National Centres for Environmental Prediction (NCEP). Only climate station data was used as the NCEP data is highly spatially smoothed and did not provide the geographic detail necessary for the purposes of this project. This analyses aim to show how climatic conditions have changed across PNG. This information includes the production of variables directly relevant to agriculture. These maps highlight regions where historical changes have been large and provide valuable information regarding changes in climatic conditions necessary for food production.

Climate station data covering the period 1960 to 2015 was obtained from the PNG National Weather Service (NWS). The location of the climate stations is shown in Figure 8.4.1. Several of the climate stations are of short temporal duration. These were later excluded or down weighed in the subsequent analyses depending on the extent of missing data.

A list of climate indices relevant for PNG agriculture was obtained from the SNA information as well as informal interviews with NARI extension staff (Table 8.4.1). The indices have been computed at each climate station and are mostly at monthly or annual level. Often missing values are produced in months where the original daily data from the climate station is missing. However, some degree of tolerance to missing data has been built into the code for calculating these indices.

The original proposal was to compare the change in frequency of these climate indices for two discreet periods: 1960 to 1984 and 1985 to 2015. However, due to the short time duration of much of the climate station data, such a comparison is not possible, so instead we have computed time trend coefficients instead, then smoothed and mapped these values. Two approaches were considered to map the values spatially. These included a simple station-by-station time trend analysis, then spatial smoothing by weighted Kriging, or possibly weighted co-Kriging with altitude. A second more sophisticated approach, which is less affected by the missing information and more effectively utilizes all the observed data, is a spatial-temporal modelling approach. A testing of the two approaches showed that the first approach was computationally more efficient and only marginally less skilful than the more complex method.

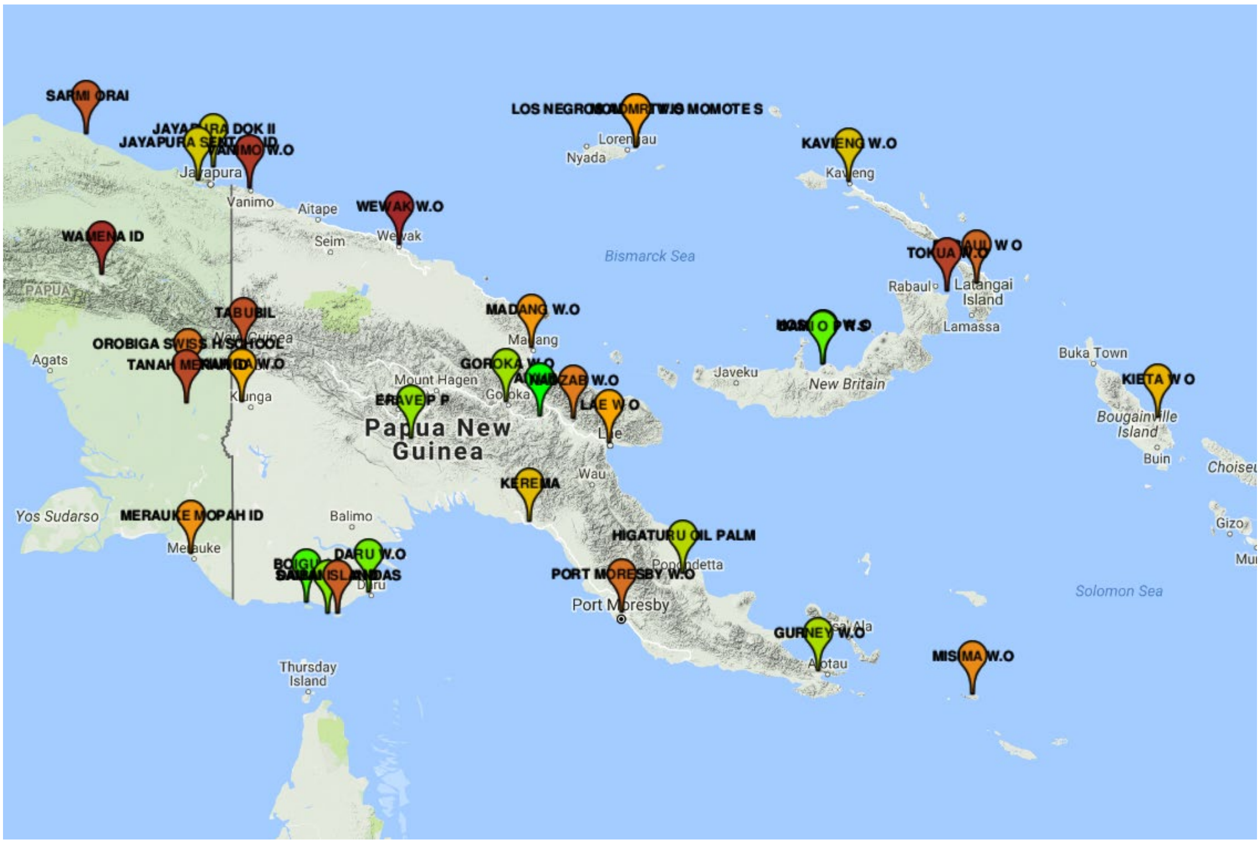

Figure 8.4.1. A map highlighting the position of all the station data considered in the spatial trend analyses.

The analysis of the data revealed a number of significant gaps and missing data issues with the operational weather station data. After careful analysis only data from 17 weather stations was deemed suitable for use in the production of the spatial trend maps.

In Table 8.4.1 a total of 38 indicators were identified for development however the limited data did not allow the calculation of a number of the indicators. In total only 11 indicators could be calculated, these have been highlighted in red in Table 8.4.1.

Table 8.4.1. Climatic indicators

Indicator name	Indicator ID	Quick definition
Frost days	**fd**	Annual count when TMin(daily minimum)<0ºC
Summer days	**su**	Annual count when TMax(daily maximum)>25ºC
Tropical nights	**tr**	Annual count when TMin(daily minimum)>20ºC
Max. Tmax	txx	Monthly/annual maximum value of daily maximum temp
Max. Tmin	tnx	Monthly/annual maximum value of daily minimum temp
Min. Tmax	txn	Monthly/annual minimum value of daily maximum temp
Min. Tmin	tnn	Monthly/annual minimum value of daily minimum temp
Cool nights	**tn10p**	Percentage of days when TMin<10th percentile
Cool days	**tx10p**	Percentage of days when TMax<10th percentile
Warm nights	**tn90p**	Percentage of days when TMin>90th percentile
Warm days	**tx90p**	Percentage of days when TMax>90th percentile
Warm spell duration	**wsdi**	Annual count of days with at least 6 consecutive days when TMax>90th percentile
Cold spell duration	**csdi**	Annual count of days with at least 6 consecutive days when TMin<10th percentile
Diurnal temperature	dtr	Monthly mean difference between TMax and TMin
Max. 1-day precipitation	rx1day	Monthly maximum 1-day precipitation
Max. 5-day precipitation	rx5day	Monthly maximum consecutive 5-day precipitation
Simple daily intensity index	sdii	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year
Number of heavy precipitation days	r10mm	Annual count of days when PRCP>=10mm
Number of very heavy precipitation days	r20mm	Annual count of days when PRCP>=20mm
Number of days above n mm	rnnmm	Annual count of days when PRCP>=n mm, n is user defined threshold
Consecutive dry days	cdd	Maximum number of consecutive days with RR<1mm
Consecutive wet days	cwd	Maximum number of consecutive days with RR>=1mm
Very wet days	r95ptot	Annual total PRCP when RR>95th percentile
Extremely wet days	r99ptot	Annual total PRCP when RR>99th percentile
Annual total wet-day precipitation	prcptot	Annual total PRCP in wet days (RR>=1mm)
Drought index 1	spei	Annual/monthly standardized Precipitation Evapotranspiration Index
Drought index 2	spi	Annual/monthly standardized Precipitation Index between [-2, 2]
Drought duration	spei95	Annual count of months with SPEI > 95th percentile

Table 8.4.1. (Cont.) Climatic indicators

Indicator name	Indicator ID	Quick definition
Drought duration	spei05	Annual count of months with SPEI < 5^{th} percentile
Diurnal temperature variation	dtv	Monthly mean temperature variation within 24 hours: max(TMax(i) - TMin(i+1), TMax(i)-TMin(i))
Rainfall in the driest season	rds	Annual mean minimal rainfall for a 31 consecutive days, time window (driest season)
Rainfall in the wettest season	rws	Annual mean maximal rainfall for a 31 consecutive days, time window (wettest season)
Temperature of the coldest season	tcs	Annual mean minimal temperature TMin for a 31 consecutive days, time window (coldest season)
Temperature of the hottest season	ths	Annual mean maximal temperature TMax for a 31 consecutive days, time window (hottest season)
Timing of the coldest season	jcs	Annual Julian day of the coldest season (31 days window)
Timing of the hottest season	jhs	Annual Julian day of the hottest season (31 days window)
Brief cold snap temperature	bcst	Annual cold snap temperature, below which at most one day TMin is within any 31 days window
Brief heat wave temperature	bhwt	Annual heat wave temperature, above which at most one day TMax is within any 31 days window
temperature of coldest quarter	tcq	Mean minimum temperature of coldest quarter
temperature of hottest quarter	thq	Mean maximum temperature of hottest quarter

The production of the trend maps resulted in some interesting and counter-intuitive discoveries.

The map presenting the monthly/annual maximum value of daily maximum temperature shows that the more extreme maximum temperatures have cooled over much of the outer islands i.e. Bougainville, New Britain and New Ireland as well as the southern tip of PNG around Alotau (Figure 8.4.2).

Warming of between 0.2°C and 1.2°C per decade in maximum value of daily maximum temperature is found over much of the western half of PNG, with greatest warming in the far west (Figure 8.4.2).

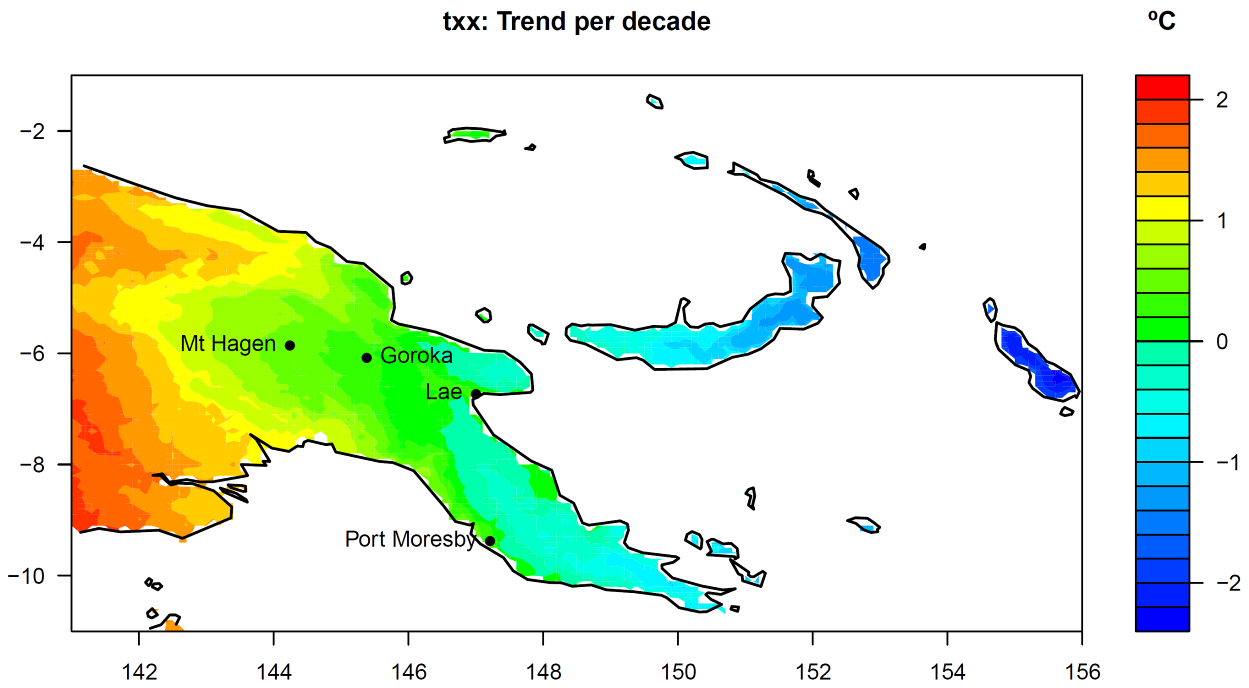

Figure 8.4.2. A map highlighting the monthly/annual minimum values of daily maximum temperature.

The map presenting the monthly/annual maximum value of daily minimum temperature shows as similar pattern of cooling and warming to the maximum temperature with cooling over much of the outer islands i.e. Bougainville, New Britain and New Ireland as well as the southern tip of PNG around Alotau (Figure 8.4.4) and warming of between 0.2°C and 1.0°C per decade found over much of western half of PNG (Figure 8.4.4).

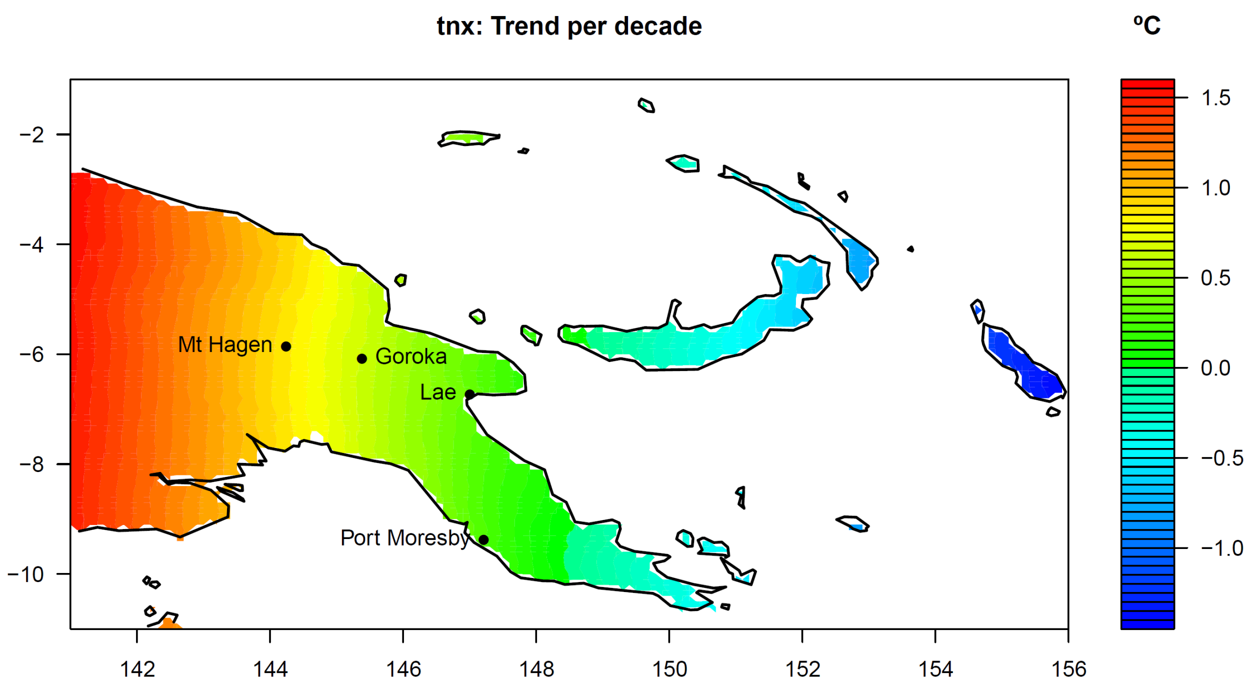

Figure 8.4.2. A map highlighting the monthly/annual maximum value of daily minimum temperature.

Monthly/annual minimum values of daily minimum temperature also show the same pattern of warming and cooling across PNG (Figure 8.4.3)

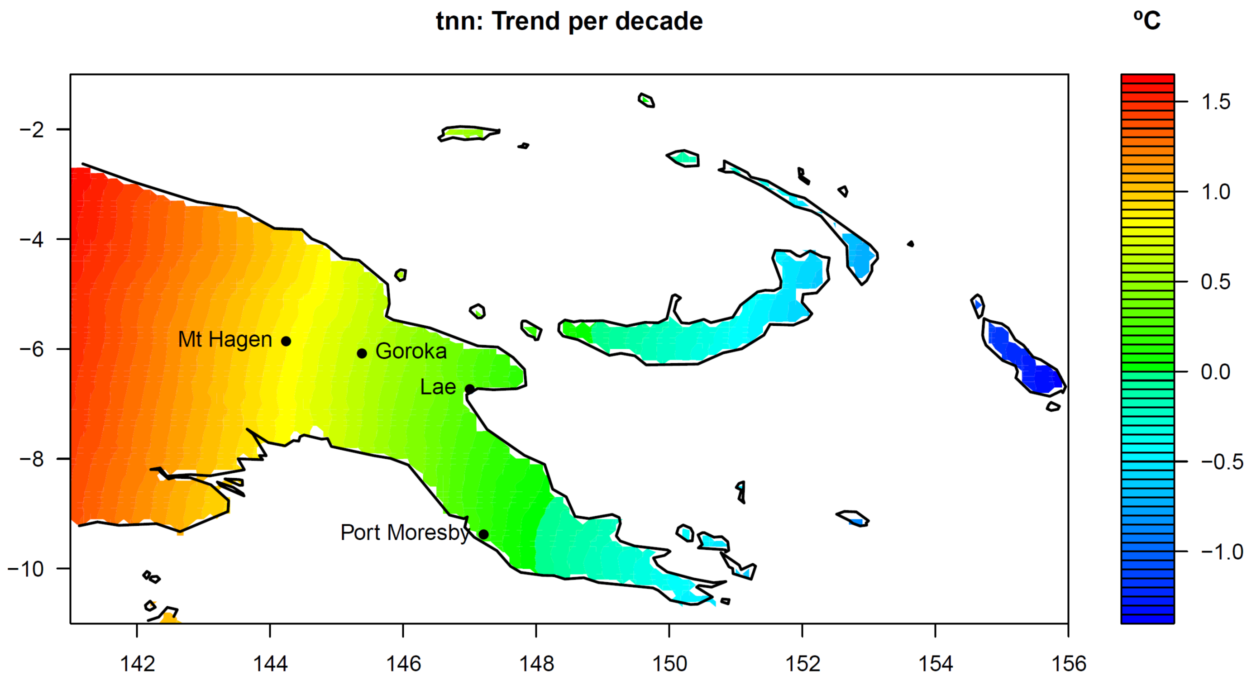

Figure 8.4.3. A map highlighting the monthly/annual minimum values of daily minimum temperature.

The map showing the trend in mean maximum temperature of hottest quarter, shows that the maximum temperatures during this period are warming by up to 0.4°C per decade across all of PNG. This result is contrary to the results of Figures 8.4.1 to 8.4.3 and would suggest strong seasonal variations in temperature change across PNG. The warming present in the hottest quarter versus the cooling found across the whole year would suggest that temperature changes during the remaining months, particularly over new Britain, New Ireland and Bougainville are cooling (Figure 8.4.4).

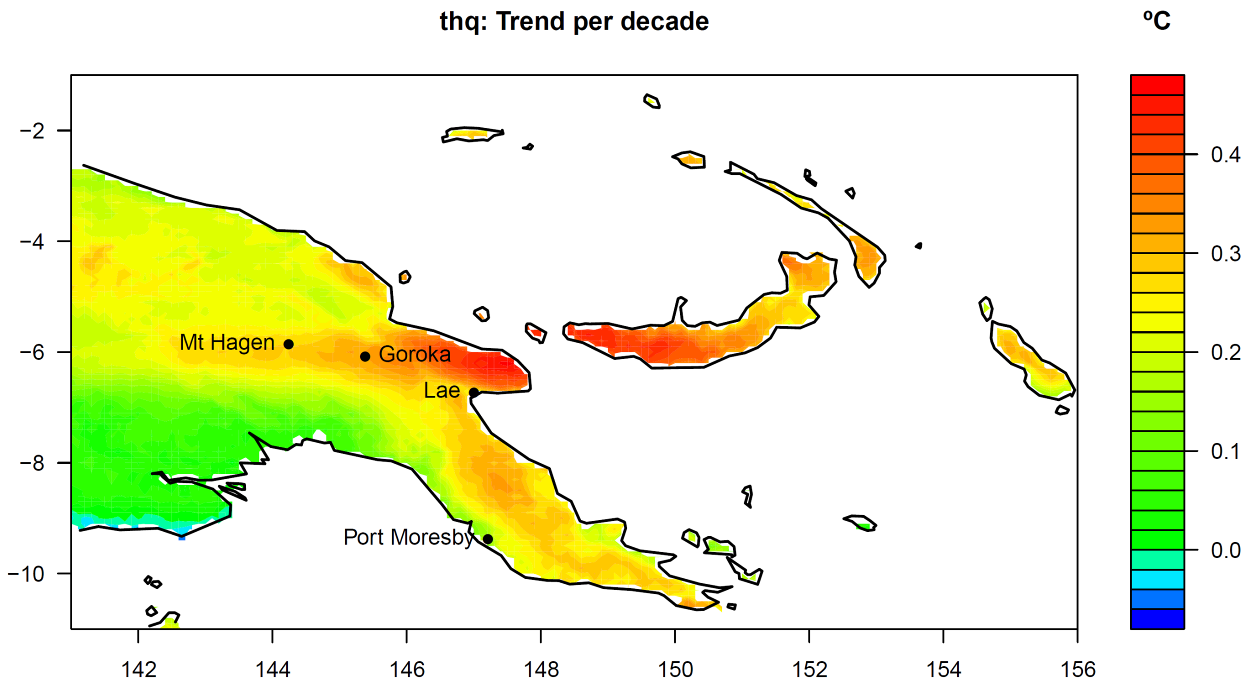

Figure 8.4.4. A map highlighting the trend in the mean maximum temperature of hottest quarter.

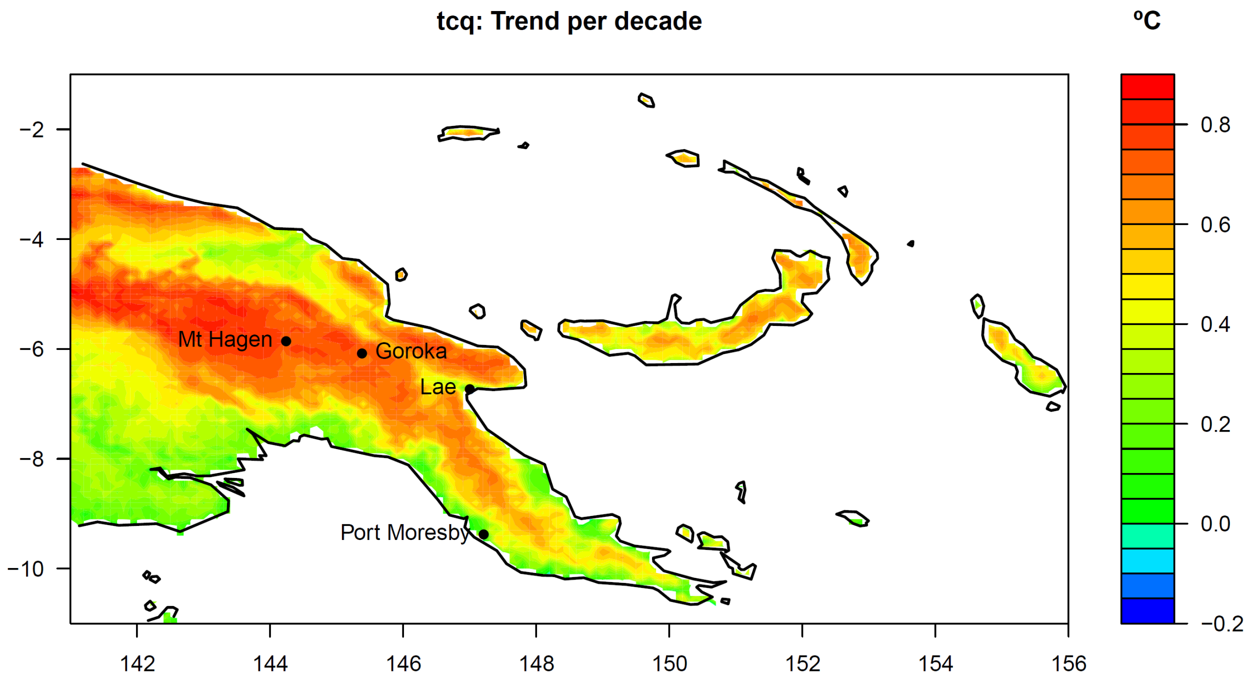

Figure 8.4.5. A map highlighting the trend in the mean minimum temperature of coldest quarter.

In Figure 8.4.5, a warming trend in the mean minimum temperature of the coldest quarter is found. This warming trend is more extensive than the mean maximum temperature of the warmest quarter trends, with warming of up to 0.8°C per decade estimated at Mt Hagen and Goroka.

Consistent with the seasonal variation in temperature change is the decline in the diurnal temperature range over most of PNG except Bougainville and the southern parts of PNG near Alotau. The trends indicating an increase in the diurnal temperature range suggest very different rates of temperature change between both minimum and maximum temperatures (Figure 8.4.6). Over most of the western half of PNG the difference between maximum and minimum temperatures has declined by up to 0.2°C per decade. This would suggest less relative cooling at night, making night-time and day-time temperatures closer.

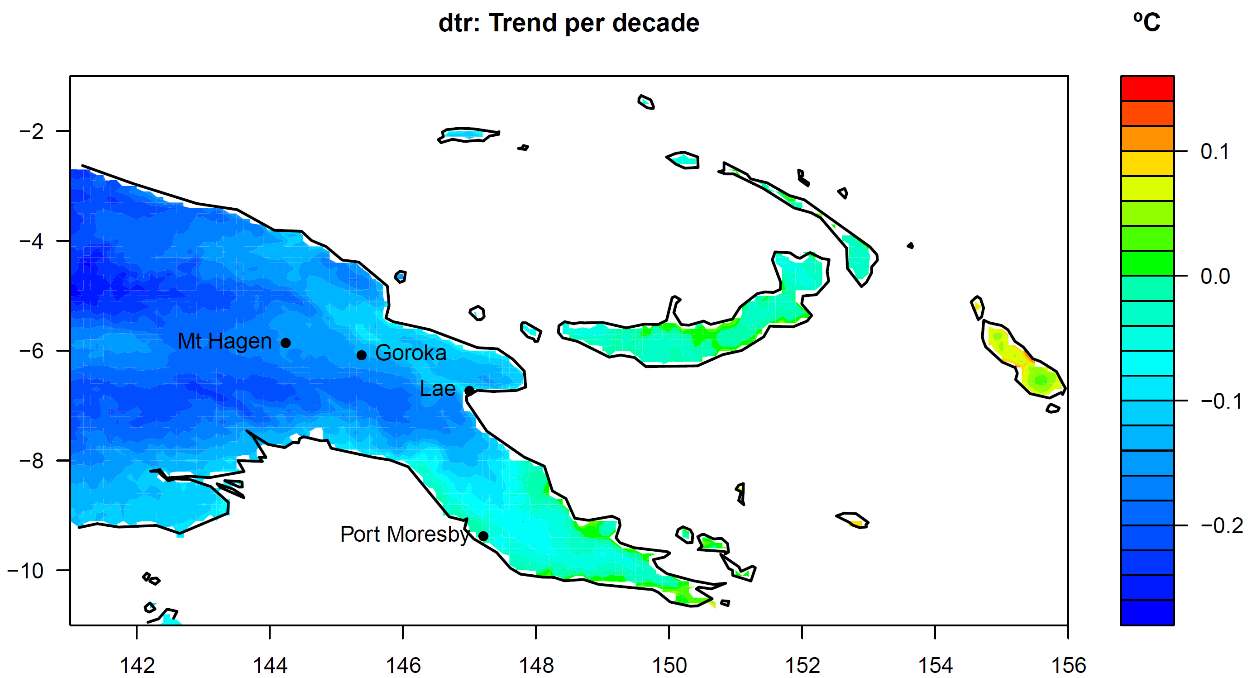

Figure 8.4.6. A map highlighting the trend in diurnal temperature range over PNG.

Despite recent drought events over the last decade, trend analyses would indicate that annual rainfall amounts have increased over almost all of PNG except for some coastal regions around Daru and south west PNG (Figure 8.4.7). In some regions this increase has been large i.e. up to 260mm additional annual rainfall in the most recent part of the record compared to the 1960's.

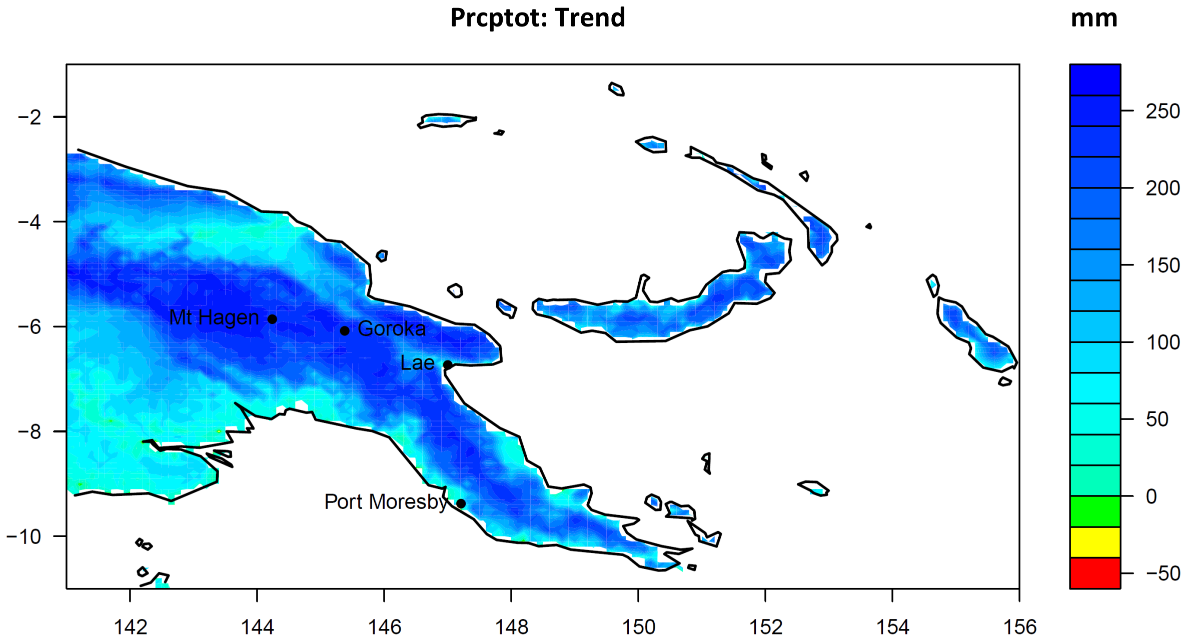

Figure 8.4.7. A map highlighting the trend in annual rainfall totals.

Analysis of the most extreme rainfall amounts, (measured by the 99th percentile rainfall amount), shows that extreme rainfall amounts have increased over much of the outer PNG islands e.g. New Britain, New Ireland, Bougainville and southern parts of PNG (Figure 8.4.8). In some instances (i.e. Bougainville) up to 80mm more now falls during extreme rainfall events than in the early 1960s.

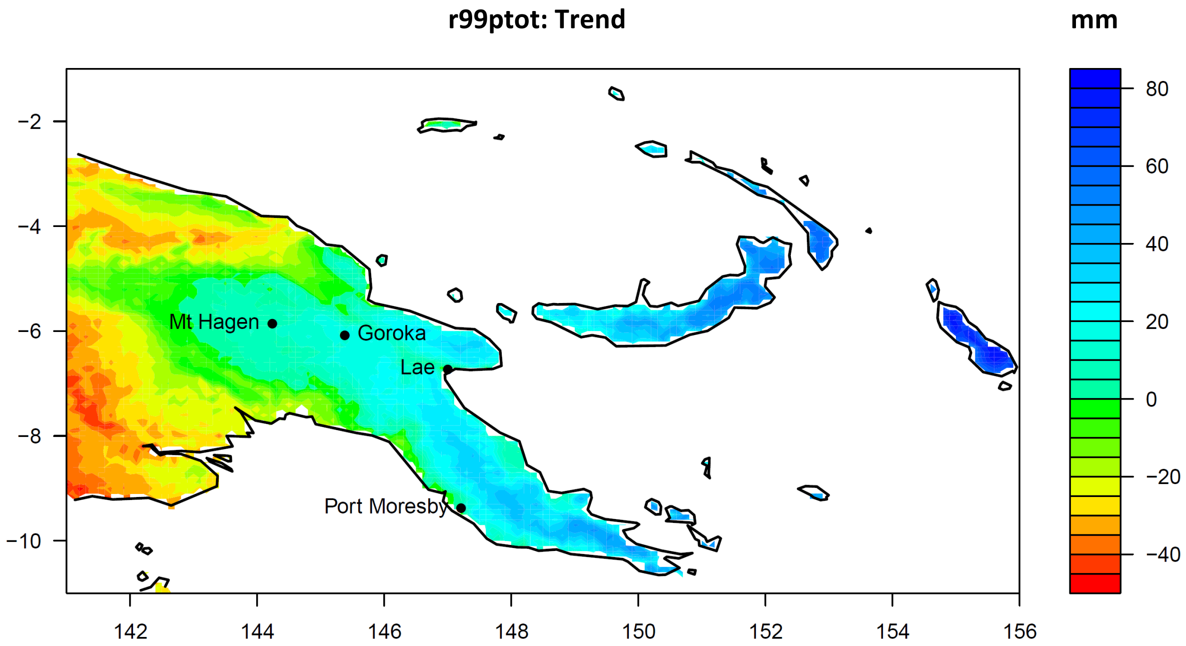

Figure 8.4.8. A map highlighting the trend in extreme rainfall (99th percentile rainfall amounts).

Trends in the Monthly maximum consecutive 5-day precipitation amount show increases of between 0.2 and 0.8 mm per decade over much of the outer islands and southern parts of PNG. West of Goroka the maximum amount of rainfall over a consecutive 5-day period has declined by as much as 0.6 mm per decade (Figure 8.4.9).

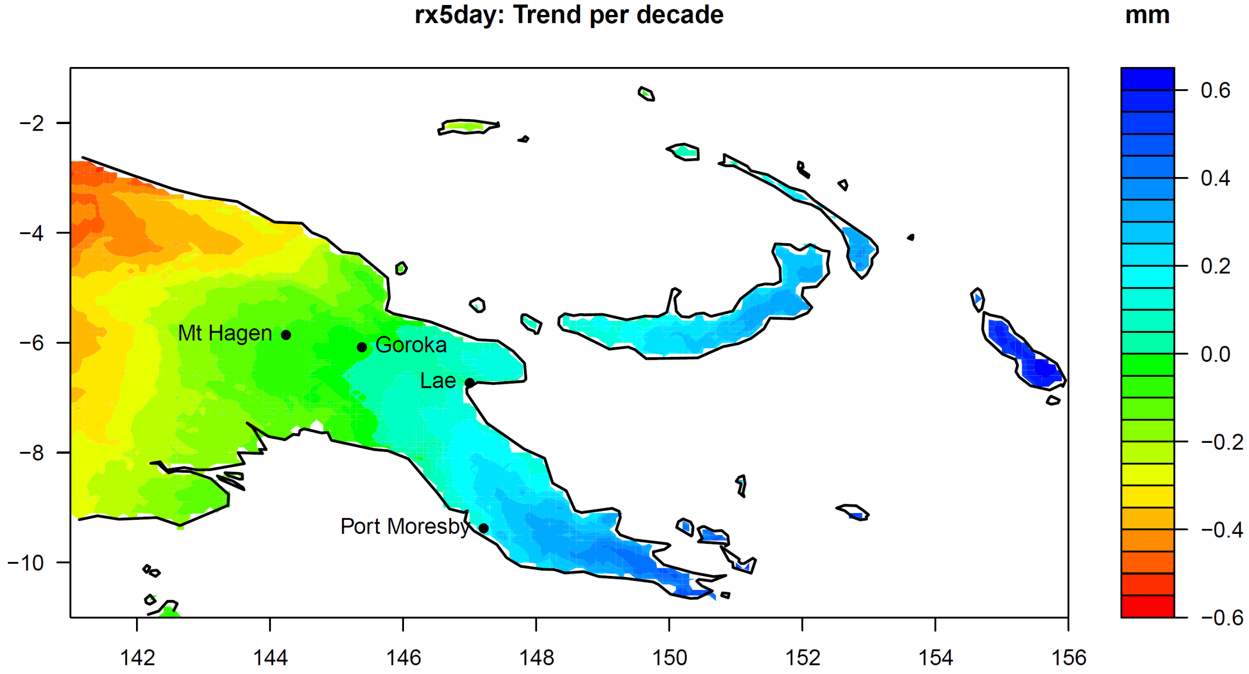

Figure 8.4.9. A map highlighting the trend in the consecutive five day rainfall amount.

Figure 8.4.10 highlights the changes in the consecutive wet days over PNG. Over the outer islands as well as the central and eastern highlands of PNG, the number of consecutive wet days has increased. Since 1980 consecutive days of rainfall are now between 0.5 and 1 day longer, across the outer island. In the south western parts of PNG the length of consecutive wet days has declined so that these events are now on average half-a-day shorter. This might account for why temperature trends have declined in these regions (i.e. increased rainfall and cloudy conditions) (Figure 8.4.8).

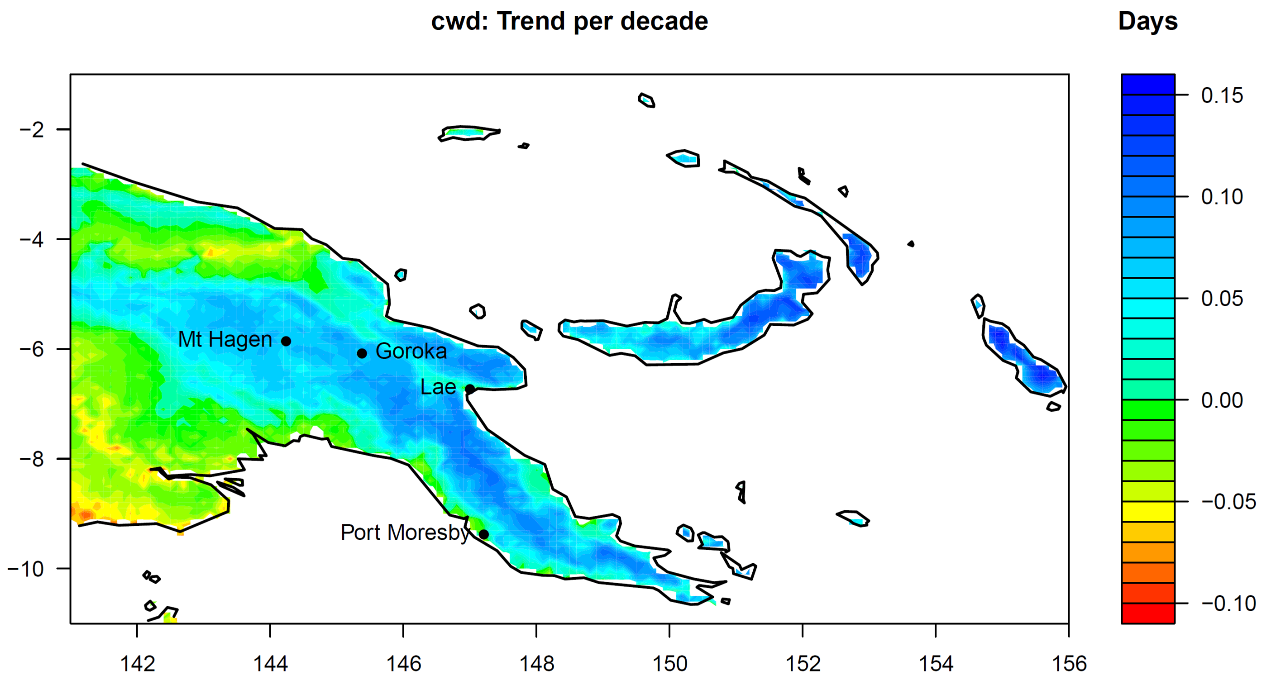

Figure 8.4.10. A map highlighting the trend in consecutive wet days.

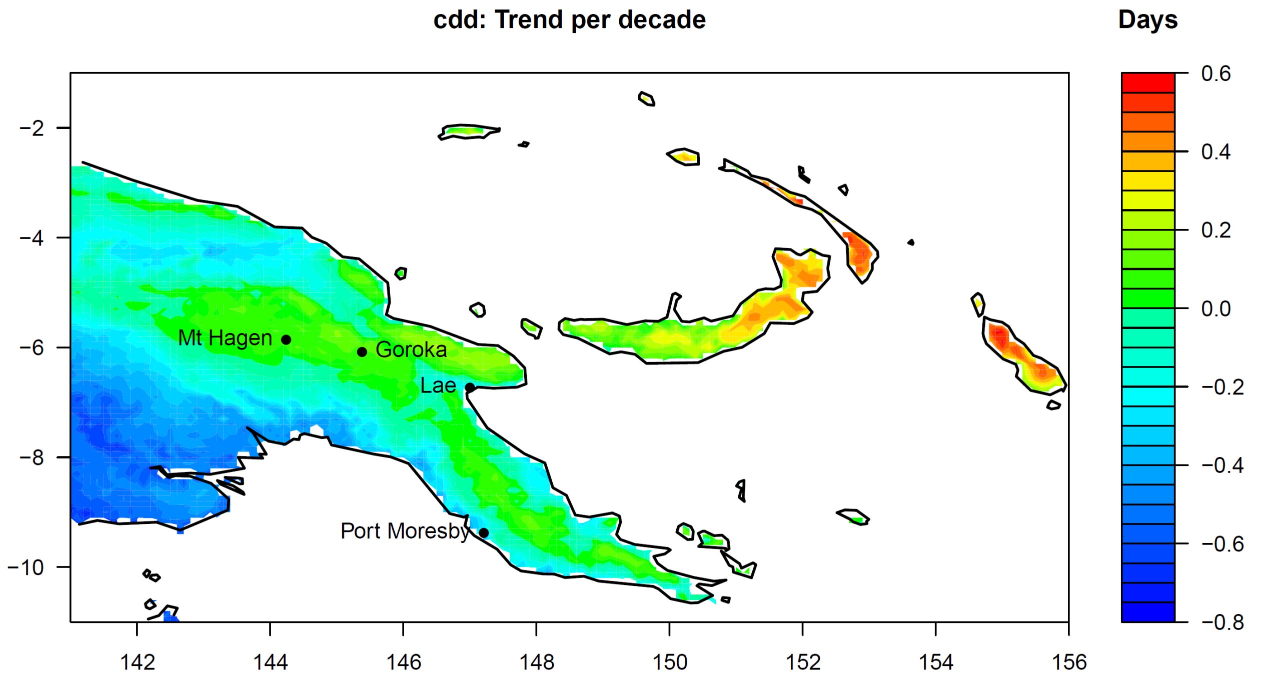

Figure 8.4.11. A map highlighting the trend in consecutive dry days.

Over much of the outer islands, southern PNG and Highlands regions, the average number of consecutive dry days has increased. The average time between rainfall events is now 1.5 days longer than it was back in the early 1960's (Figure 8.4.11).

The south western parts of PNG do show a shortening of the mean consecutive dry spell length, with these dry days now 2 days shorter than in the earlier 1960's.

8.5 Climate Resilient farming options

This section provides a set of 'no-regrets' farming options for three case study sites in Eastern Highlands Province. Background material includes sources of information on the physical environment, agricultural production and cash income in Papua New Guinea (PNG); information on Easter Highlands Province (EHP); and on the three study sites. This section then discusses options to help villagers make their agriculture more resilient in both particularly wet and particularly dry years, where no reliable medium-term weather forecast is available to them. Where reliable medium-term forecasts are available, this section also makes some suggestions as to what farmers can do to accommodate the changed rainfall conditions.

This section represents a mostly 'desktop' exercise, based on over 47 years of local experience by members of the team (R.M. Bourke) into research, development and training in PNG. Field visits were made to the three target areas in the province (Ifiyufa, Okapa and Ontobura) and DAL and provincial DPI staff in Goroka were interviewed. The field visits were conducted by Dr Reuben Sengere and Ms Rebecca Amira, both of whom are based at Aiyura. An example of the issues covered in the interviews is contained in Appendix F.

This section comprise of four broader sub-sections. These include:

- Sources of information on physical environment (altitude/temperature, rainfall, slope, soils) agricultural production, cash income in Papua New Guinea.
- Background on Eastern Highlands Province, including physical environment, demography, food and agriculture production, vulnerability to impact of climate change and climate variability, and agricultural outreach on climate change and climate variability.
- Some background on the three target locations (Ifiyufa, Okapa and Ontobura). This covers the location, physical environment, population, food production, cash income, market access and cash income, vulnerability to climate change and climate variability, and agricultural outreach in the area.
- Recommendations on research for climate-smart agriculture in Eastern Highlands. This considers three situations:
    1. Options to make current agricultural systems more resilient to very wet or very dry years in the absence of reliable medium-term weather forecasts.
    2. Options to make current agricultural systems more resilient in very wet periods where reliable medium-term weather forecasts are available
    3. Options to make current agricultural systems more resilient in very dry periods where reliable medium-term weather forecasts are available

Background on Eastern Highlands Province

Physical environment

As the name of the province implies, Eastern Highlands Province (EHP) is the most easterly of the seven provinces in the central highlands. The total land area of the province is about 11,300 km^2.

Agriculture is conducted over an altitudinal range of 300 to 2400 m, but most people live and farm over a narrower range, 1500-2000 m. The narrow band of agricultural activity means that altitudinal differences are small, and associated temperature differences, have a lesser effect on agriculture in EHP than in the other highland provinces. Annual rainfall varies from 1800 to 2500 mm, with a range from no dry months to five dry months on average each year. In the south of the province, the mean annual rainfall is 2300-2500 mm with a short dry season of only one or two dry months each year. In the northern valleys between Kainantu and Goroka, the mean annual rainfall is lower (1900-2200 mm) and the dry season is a little longer. In the Henganofi area, the rainfall is lower again (1800 mm) and the dry season is five months long on average. The northern part of the province is the driest part of the highlands and has the longest dry season.

Three sub-regions may be distinguished based on fallow vegetation, the main landforms, access to services and villagers' cash income. These are the Asaro Valley and the other northern valleys, floodplains and dissected fans; the middle hills, mountains and fans; and the southern hills and mountains. The population density in these three sub-regions is medium to high, medium and low respectively (Table 1, Bourke *et al*., 1994). Access to services and cash income is greatest in the first sub-region, intermediate in the second and lowest in the third.

Demography

The 2011 census recorded a provincial population of 579,825 people in 136,992 households, with a mean of 4.2 people per household (NSO, 2013). If the population is growing at a rate of 2.7% per annum, the projected provincial population in mid-2018 would be about 696,000 people.[4] There are two larger urban centres, as well as smaller government and mission stations. The provincial capital Goroka had a recorded population of 23,277 people in mid-2011, although an unknown number of peri-urban dwellers were recorded as living in rural areas when in fact they lived on the edge of Goroka. The second town is Kainantu (7287 people in 2011).

The highest rural population densities on agricultural land are in the Asaro, Gafutina and Karmanuntina valleys, with over 200 people/km^2; densities are moderate (about 100-150/km^2) in the Dunantina, Ramu and Bena valleys; and the population density is low to moderate in the centre and south of the province. There has been significant in-migration to parts of the province over the past 50 years, with people moving from more remote locations in the province to locations with more productive environments and better access to markets and services. Many people have moved into the Upper Asaro Valley and smaller numbers into the Upper Ramu Basin and Aiyura Basin near Kainantu.

Food and agricultural production

Sweet potato is the most important food for almost all rural villagers (99.7%) in province, with the minor exception of several valleys south of Ontobura and Okapa where a mix of sweet potato, yam and taro are the most important foods. Other food crops grown and consumed in much smaller quantity than sweet potato include banana, cassava, taro, yam, corn (maize), peanuts, sugarcane, *marita* pandanus fruit and *karuka* pandanus nut. Numerous vegetables are grown including highland *pitpit*, amaranthus, common bean, winged bean, rungia, cucumber, oenanthe, pumpkin tips and *aibika*.

The agricultural systems used to produce food differ depending on the physical environment and population density. Land use is most intensive in the Asaro Valley, west of Goroka. It is more intensive in the northern valleys, less so in the middle hills and valleys and least intensive in the southern hills, mountains and plains. Natural fallows are the basis of soil fertility restoration in all parts of the province. This is supplemented by a rotation of sweet potato (occasionally yam) with peanuts (sometimes winged bean) in the northern grassland valleys. This technique is an important one for over 50% of the rural population. To the west of Mt Michael, and continuing west into Simbu Province, soil fertility is maintained by fallows of casuarina trees (which fix atmospheric nitrogen). Only 7% of the rural population plant significant number of casuarina trees in their food gardens. Irrigation of taro plots was practiced in a few places in the Lamari Valley until about 1990, but this practice seems to have ceased. There is evidence of extensive irrigation systems used in the past, presumably prior to the replacement of taro with sweet potato about 250-300 years ago. The main sweet potato gardens are not planted seasonally, except in the driest areas near Henganofi where most gardens are

[4] A population growth rate of 2.7% pa has been used here as this was the growth rate between the two most reliable censuses held in PNG (1980 and 2000) (NSO, 2002). The growth rate between the 2000 and 2011 census was reported as 3.1% pa (NSO, 2013). There are strong indications that the data from the 2011 census was not very reliable. The National Statistician stated in 2016 that the total population of PNG could be anywhere between 8 and 10 million people.

planted in September to December. Gardens of mixed vegetable (without sweet potato) are commonly planted and these are planted seasonally in September-October.

Agricultural labour varies for women and men. Men are mostly responsible for clearing land from cane grass and woody regrowth fallows and for digging drains (which are used extensively in the northern valleys). Women do most of the planting and harvesting of sweet potato and other food crops. Both men and women participate in establishing, maintaining and harvesting coffee plots. In the grassland areas in the north and centre of the province, there is greater involvement by women than men in food production, whereas in the southern part where woody regrowth fallows are more commonly used, men tend to have a greater involvement in food production. In general, men tend to have somewhat greater inputs into coffee production and gain a disproportional share of income from coffee. Marketing of fresh food is dominated by women, but men are more engaged in long-distance marketing, including sale of sweet potato, potato, cabbage in Lae and Madang, as well as in transporting lowland produce to highland markets for sale. As always, there are exceptions to these broad patterns of gender inputs into agriculture.

The Highlands Highway runs through the northern part of the province, hence access to markets in Goroka, Lae, Madang and elsewhere is good in this part of the province. Market access is reasonably good in the middle part of the province, but it often hampered by the poor state of repair of rural roads. Market access is poor to extremely poor in the south of the province, where it can take villagers two to three days walk to carry produce, such as coffee, to a road head in the province or in neighbouring Morobe Province.

Cash income follows a similar pattern to market access. In the northern valleys, most rural villagers gain reasonably high cash incomes from the sale of fresh food, coffee, firewood, pigs and some tobacco. In the middle part of the province, cash income is lower, with coffee being the most important source of income. Cash income is low to very low in the southern sub-region, with limited income from local sales of fresh food and pigs and some coffee. Overall, coffee is the most important source of income for rural households, but marketed fresh food and other agricultural produce are increasingly important.

There is limited information on safety nets in the province, as elsewhere in PNG. A recent study on poverty, risk and assistance from others ('informal insurance') was conducted by Rogers (2015) in remote Andakombi Village in the far south of the province in Obura-Wonenara District, Eastern Highlands Province, near the border with Gulf Province.

She reported that households in her study area face extraordinarily high levels of risks and are very weakly networked. Geospatial factors interacted with inadequate government services, low levels of human capital, a lack of markets and underdeveloped family and social capital to contribute to the community members living in poverty, with limited household assets. The poorest within the study area were relatively geographically disadvantaged, more food insecure, more exposed to serious risk, more reliant on consumption reducing strategies and less insured through social networks (Rogers, 2015).

Rural villagers are vulnerable to both climate variability and long-term climate change, particularly increasing temperatures and changing rainfall patterns. Many villagers in Eastern, near Goroka, have commented that rainfall seasonality is less predictable than in the past, that is, there might be significant rain in the normally drier months (June to August) or there might be a short dry period in the wetter months (December to April). Dr. Mike Bourke first recorded such comments in EHP in 1990. People are not saying that the rainfall is higher or lower, just that the seasonal patterns are changing. The increasing temperatures are obvious to most rural people, with many commenting on the fact that tree crops which previously grew, but did not flower and bear fruit or nuts, are now bearing at higher altitudes. Villagers have commented on the changing behavior of coconuts, mango, breadfruit and betel nut. The bearing season for coffee and *marita* pandanus fruit is said to be more erratic than in the past when the production periods could be predicted. These assertions have not been tested by analysis of coffee sales.

The only meteorological station in the highlands with almost 80 years of continuous data is located at the NARI research station at Aiyura, although the location of the weather recording equipment was moved from the edge of the Aiyura Basin to the bottom of the Basin in the early 1960s. Note that other weather stations in the highlands, such as Goroka or Mt Hagen, have much shorter data runs from the same location. Even a quick look at the temperature data from Aiyura confirms that minimum and maximum temperatures have increased by over a degree since the 1970s. The analysis of rainfall trends for Aiyura (presented in section 8.2) shows clear changes in annual and seasonal totals as well as wet and dry periods. It would be worthwhile to analyse the production patterns of coffee over the past 50 years, particularly data from Aiyura research station where production does not vary with higher or lower prices paid to growers. There is no long-term data on production of tree crops such as *marita* pandanus or *karuka* pandanus.

Extremes of rainfall currently present the greatest threat to food production. People in the northern part of the province, particularly in the dryer and more seasonal Henganofi and Bena Bena areas are vulnerable to deficit of rainfall. The agricultural systems in the driest areas are organized to cope with an annual period of low rainfall. In the past, this included plantings of yam and banana, as well as the staple food sweet potato. Over the past 50 years, people have adopted relatively fast maturing corn as an important food as well as cassava, which is well adapted to rainfall extremes. Since the early 1960s, villagers have used cash income from coffee and other sources to purchase food when subsistence production is inadequate.

However, droughts, particularly the major ones in 1997 and 2015, as well as smaller ones in other years, including 1972 and 1982, cause stress on food supply. Food deficits are greatest in the driest parts of the province, that is the Henganofi to Bena Bena area. People can cope with a short period of low rainfall in the middle of the calendar year when there is cash income from coffee sales. However, an extended dry period that continues late into the calendar year causes considerable stress once the coffee harvesting season has finished and households have less cash income. This happened in the major 1997 drought, when some people survived by eating the basal portions (corm) of banana plants.

While the stress from extended dry periods is greatest in the Henganofi to Bena Bena area, villagers in all parts of the province suffered from food shortages in major droughts. The impact is greatest on those with limited cash income, particularly in the far south of the province. People who can access cash from selling coffee, fresh foods or other items purchase food, particularly imported rice, when subsistence production is inadequate.

Periods of extended high rainfall and saturated soils also result in food shortages, as elsewhere in the highlands. Episodes of subsistence food shortage result in villagers increasing the rate of planting of food gardens, which results in a period of particularly abundant food supply. Women then reduce the planting rate and that results in a second food shortage about two years after the first. The long-term research that established these planting cycles was conducted in communities in this province and in Southern Highlands Province, but this pairing of subsistence food shortages has been documented in all highland provinces (Bourke, 1988; Section 5.20 in Bourke and Harwood, 2009).

Agricultural outreach and communication around climate change and climate variability

The national Department of Agriculture and Livestock (DAL) Regional Office is mandated to provide services and support to Provincial DPI Offices across the highlands. The Division of Primary Industry in Eastern Highlands is responsible for agricultural outreach in the province.

There is currently no seed multiplication program in Eastern Highlands Province. Currently the only way farmers can access seeds is by trading. Neither the DAL regional office in Goroka nor the provincial DPI office have programs targeting the impact of climate change or climate variability.

The National Broadcasting Commission has a FM transmitter in Goroka. The lack of AM transmitters across the highlands means that the FM transmitters allow NBC Eastern Highlands to broadcast to a maximum of 50 km radius from Goroka. So, villagers in Ifiyufa can receive the FM station, but not those at Okapa or Ontobura.

There are numerous small church activities in Eastern Highlands Province and there is an opportunity for churches to be engaged to provide services. Many NGOs have a presence in Eastern Highlands Province, including Red Cross, CARE and Oxfam. The provincial capital, Goroka, is also home to several national institutions including Fresh Produce Development Agency, Coffee Industry Corporation and the Department of Agriculture and Livestock Highlands Regional office.

Ifiyufa

Location and physical environment. The Bena Valley is located east of Goroka and Ifiyufa is located approximately 45km north of Goroka. The area is located administratively in Unggai-Bena District, with three Local Government Areas (LLGs) in the district (Lower Bena, Upper Bena, Unggai).

Most inhabited locations are in the range of 1400 to 1600 m altitude, with some people living somewhat higher, particularly closer to the ‘Bena Gap’ at the head of the valley. Mean annual rainfall is about 1900 mm per year, with a distinct dryer period in June, July and August in most years. The landforms most commonly used for agriculture are floodplains, plains and colluvial fans. The soils are generally productive. Analysis of the productive potential found that land potential in the area is very high (see Hanson *et al*., 2001, pages 159 and 169).

Population. The population in the area was 43,665 living in 10,600 households in mid-2011. This was split between Lower Bena Rural LLG (26,330 people) and Upper Bena Rural LLG (17,335 people). At a growth rate of 2.7% per year, the projected mid-2018 population in the two LLGs is 52,600 people, with a population density of 75 persons/km^2.

Food production. Land use is intensive in the Bena Bena Valley and is dominated by sweet potato production. Typically, 3 to 5 plantings are made before the land is fallowed for short periods of 1 to 4 years under short grasses. Productivity is maintained through a rotation of sweet potato with peanuts. Other agricultural techniques include planting in small mounds, typically 30 cm high, soil tillage and the use of long drained beds. Vegetable crops are planted in sweet potato gardens after a fallow and in ‘mixed gardens’ where a wide range of food crops are planted, but not sweet potato. Most people also maintain a small garden near their household for vegetables.

Market access and cash income. Villagers have good access via a well serviced (e.g. buses and taxi’s) tarred road to Goroka and to Lae via the Highlands Highway. Cash income is moderately high, with sale of coffee and fresh food being the most important sources of cash income for most villagers. Pineapple has become a significant cash crop in the area in the past decade. There are an increasing number of oranges being grown for sale in Goroka market. A study of trade in the Bena Gap area (at the top of the Bena Valley) in 1970-71 showed extensive movement of goods, including agricultural produce, across ecological boundaries (Keil, 1974:46-49, 62-70, 197). It is not known to what extent this trade continues, but it likely that some goods continue to be traded to villagers living in different environments.

Vulnerability to climate change and climate variability. Villagers in the Ifiyufa area report that the rainfall pattern has changed since the 1980s. They say that the seasonal rainfall patterns are less predictable. In the absence of any long-term recording stations in this area, it is not possible to comment on whether the total annual rainfall has increased or decreased. Given the relatively long dry period each year in the context where sweet potato and other food crops are not stored, villagers are vulnerable to food shortages if there are longer dry periods each year or if the frequency of drought associated with El Niño events increases.

Okapa

Location and physical environment. Okapa station is located about 50 km (as the *pisin* flies) southeast of Goroka, but much longer by road. The area is located administratively in Okapa District, with two Local Government Areas (LLGs) in the district (East Okapa Rural, West Okapa Rural).

People live and farm between 1400 and 2200 m altitude, with most living in the range 1500-2000 m. Mean annual rainfall is about 2300 mm per year, with a somewhat dryer period in June and July in most years. The most common landforms are hills and mountains. The soils are moderately productive. Analysis of the productive potential found that land potential to be moderate, with a limited area of higher potential south and southeast of Okapa station (see Hanson *et al*., 2001, pages 159 and 168).

Population. The population in the area was 73,400 living in 16,270 households in mid-2011. This was split between East Okapa Rural LLG (41,415 people) and the West Okapa Rural LLG (31,978 people). At a growth rate of 2.7% per year, the projected mid-2018 population in the two LLGs is 88,400 people, with a population density of about 92 persons/km^2 in the north of the district. There has been significant out-migration from the district in the past because of the lack of cash earning opportunities.

Food production. Land use is low intensity and is dominated by sweet potato production. Typically, 3 to 5 plantings are made before the land is fallowed for periods of over 15 years under grass and woody regrowth. Productivity is maintained by natural fallows. Other agricultural techniques include planting in small mounds, typically 30 cm high, and soil tillage. Vegetable crops are planted in sweet potato gardens when land is opened up after a fallow and in 'household gardens' near people's house.

Market access and cash income. There is un-sealed road access to both Goroka (approximately 110 km) and Kainantu (approximately 35km) from Okapa Station. However, effective access to these towns and the Highlands Highway varies considerably over time, depending on maintenance of the roads. Cash income is modest for most villagers, with sales of coffee and some fresh food being the most important sources of cash for most villagers. Cash income is much less in the far south in the district, particularly in locations with no road access.

Vulnerability to climate change and climate variability. There are no indications of changes in rainfall patterns in recent decades. People have suffered from food shortages in major drought, particularly in 1997-98. The most vulnerable communities are those with very low cash income as villagers do not have the capacity to purchase food when subsistence food production fails.

Ontobura

Location and physical environment. Ontobura is located east of Okapa and south of Kainantu. The area is located administratively in Obura-Wonenara District, with two Local Government Areas (LLGs) in the district (Lamari Rural and Yelia Rural). Obura is in Lamari Rural LLG.

Most inhabited locations are in the range of 1400 to 1800 m altitude, but agriculture is conducted in a wider altitude range (900-2000 m). Mean annual rainfall is about 1900 mm per year, with a somewhat dryer period in June and July in most years. The most common landforms are hills and mountains. The soils are moderately productive. Analysis of the productive potential found that land potential to be moderate, with potential limited by steep slopes (see Hanson *et al*., 2001, pages 159 and 167).

Population. The population in Lamari Rural LLG was 17,850 living in 3,655 households in mid-2011. At a growth rate of 2.7% per year, the projected mid-2018 population in this LLG is 21,500 people.

Food production. Land use intensity in the Obura area ranges from low (below 1600 m altitude) to very low (above 1600 m). Sweet potato is the most important crop in most places. Until about 1980, taro and yam were also important food crops in part of this area. This remains the situation in the Imani Valley (Aziana mission area) south of Obura and the Lamari Valley. Taro and yam have gradually been replaced by sweet potato over the past 60 years. Other food crops include banana, taro, yam, *marita* pandanus, *karuka* pandanus nut and numerous indigenous and some introduced vegetables.

Fallow vegetation is short grasses below 1600 m and a mix of grass and woody regrowth above 1600 m. Cropping periods range from 2 to 5 years. Fallow period is 5-15 years below 1600 m altitude and over 15 years above 1600 m. Drains are commonly dug to remove excess water in food gardens. Household gardens are more common above 1600 m altitude. Some taro plots were irrigated in the grasslands on the sides of the Lamari Valley until about 1990 (see Boyd, 1975, 119-120; Loving, 1976; Hays, 1974, 54) This practice was revived briefly during the 1997 drought, but it seems that people are no longer irrigating taro plots.

Market access and cash income. Obura mission station is connected to the Highlands Highway and Kainantu town via Aiyura. If the road has been maintained, the journey can be done is under two hours, but the road is often in a poor state of repair. Hence access to markets tends to be limited. Villagers living further from Ontobura have even poorer access to markets and services. Some coffee is sold from the area together with minor quantities of fresh food and firewood. Overall, cash income levels are low. They are somewhat higher for villagers living between Aiyura and Ontobura.

Vulnerability to climate change and climate variability. Food production on the steep sides of the Lamari Valley between 1000 and 1600 m altitude is vulnerable to dry conditions. Therefore, irrigation was practiced in this environment in the past. If there are longer periods of low rainfall as the climate changes (and we do not yet know this), village food supply in this environment is likely to be less secure. People are more vulnerable in the Lamari Valley than north of Obura mission, as there is no road access. Hence, they have lower levels of cash income and have much less capacity to purchase rice and other food when subsistence food production is threatened by drought.

Recommendations on research for climate-smart agriculture in Eastern Highlands Province

Options to make current agricultural systems more resilient in very wet or very dry years in the absence of reliable medium-term weather forecasts

Here we make suggestions for options to make current agricultural systems more resilient to very wet or very dry years in the absence of reliable medium-term weather forecasts being available for rural villagers.

Greater access to cash income

Access to cash provides one of the best safety nets for rural villagers when subsistence food production is inadequate, for whatever reason. During food shortages caused by drought and frost in the highlands over the past 50 years, villagers who can access cash have been able to ‘buy their way out of trouble’, that is, to purchase food when their sweet potato and other crops have failed. Those who could not access cash suffered the most. Helping villagers increase their access to cash is not the focus of this study. Nevertheless, some options are noted here for the record. These include:

- Improved production of existing cash crops, for example, applying flowering hormone to induce out-of-season production of pineapples in the Ifiyufa area. Growers selling fruit out-of-season would be able to sell their produce faster and to achieve higher prices.
- Improved marketing of coffee, with production and sale of higher quality produce being sold, for example as Fairtrade coffee.
- Production and sale of sweet potato at higher altitude locations (over 1800 m altitude), particularly in the Okapa area.

Broader range of staple food crops and cultivars

Production of a greater range of staple food crops or cultivars of existing food crops to supplement the staple food, sweet potato, would increase resilience by reducing the dependence on a single staple food. Sweet potato is particularly vulnerable to excessively high moisture. Tuber yield is also reduced during extremely dry conditions, as occur in major droughts. As well, tuber yields are commonly reduced following drought-breaking rain. This is because there is usually a flush of nutrients, including nitrogen, following a drought. The extra nitrogen is generally favourable for crop production. However, excessive nitrogen on sweet potato often results in excessive top growth at the expense of tuber production and tuber yields decline after a drought (Kanua and Bang, 2001).

Options for villagers to increase the range of staple food crops or cultivars of existing food crops include:

1. Introduce and plant large areas of sweet potato cultivars which are productive under a wide range of soil moisture conditions

One such cultivar is Sinato (also known as ‘I don’t care’ in the PNG highlands). The World Bank-funded Drought Impact Management Project at Aiyura identified other sweet potato cultivars which produce fairly stable tuber yields under a range of environmental conditions (see Humphrey, Ernest and Demerua, 2001 for a description of that project). Other cultivars suitable for highland conditions which provide stable tuber yields under a range of soil moisture conditions were identified by NARI scientists in the 1990s (Guaf *et al*., 1998; Van Wijmeersch, 2001). The best person to advise on suitable sweet potato cultivars is Mr Elick Guaf, formerly a sweetpotato specialist working with NARI, who recently retired from NARI and is living near Lae.

2. Planting and consumption of suitable cultivars of cassava

Cassava produces under a wide range of soil moisture conditions. It produces tubers in very dry conditions, when other food crops fail. Unlike sweet potato, tuber production is not impacted greatly by high soil moisture and it also produces a high yield when soil moisture is particularly high. Thus, planting larger areas of cassava would enhance food security under both abnormally dry or wet conditions. It is not a popular food in the PNG highlands, but people can consume it when sweet potato is scarce. A bonus is that tubers can be fed to pigs under normal conditions, but diverted to feed people when sweet potato is scarce. Suitable cultivars need to be identified for highland conditions, as has been done in the lowlands (Grant and Allen, 2001; Grant, Allen and Wiles, 2004).

3. Planting hardy banana cultivars

Banana is another food crop which is productive under a wide range of soil moisture conditions, again in contrast to sweet potato which is particularly vulnerable to excessive soil moisture. The ABB triploid cultivars, such as Tukaru and Jawa, are particularly hardy and productive under different soil moisture conditions. Traditionally, the ABB cultivars were not grown in the highlands, with most cultivars either AA diploids or AAA triploids. Hence more planting and consumption of these cultivars would increase food security under a range of soil moisture conditions.

4. Planting West African yam (*Dioscorea rotundata*)

West African (or white) yam (*Dioscorea rotundata*) was introduced into PNG in 1986 (Risimeri, Gendua and Maima, 2001). Planting of this yam species has spread over the past 30 years, including in the highlands. Yams are productive when soil moisture is low and, while evidence in the highlands is scarce, this species appears to be productive under a range of soil moisture conditions, as it is being grown in particularly wet as well as seasonally dry locations in the lowlands. It would be worthwhile distributing planting material of white yam and evaluating its performance under a range of soil moisture conditions.

5. Maintaining larger stocks of corn planting material

Corn (maize) is a very useful component of more resilient food production systems. This is because corn matures in about 100 days at 1600 m altitude, which is very much faster than sweet potato or other staple foods. As well, the cobs contain more protein than sweet potato and other root and tuber food crops. Thus, if larger areas of corn are planted in normal years, more seed is potentially available to plant following disruption to food supply caused by drought or excessively wet conditions. If corn is planted as conditions return to normal, then food is available while sweet potato and other food crops are still maturing. Planting large areas of corn after a food shortage, particularly after a drought, is one of the most effective ways of reducing the impact of the food shortage.

The South East Asian cultivar Suwan produces well under PNG highland conditions and already has some penetration in local markets. Planting material is available from the Department of Agriculture and Livestock station at Erap in the Markham Valley.

6. Planting food producing tree crops in lower altitude locations

As temperatures increase rapidly in the highlands, some tree crops are now producing food where previously the trees grew but fruit was not produced. These include coconuts and breadfruit. It is suggested that, at locations at 1500 m and lower, some of these trees be planted. If they do not produce now, they are likely to do so as temperatures continue to increase. Coconut palms are now bearing a few nuts as high as 1600 m whereas 30 years ago, they did not usually bear nuts at above 950 m. Similarly, breadfruit is now bearing in the highlands above its previous usual upper limit of 1250 m (Bourke, 2010, Table 5). The type of breadfruit grown on the New Guinea mainland produce nuts, whereas those grown in the New Guinea islands produce edible flesh. It is suggested that some planting material of flesh-producing types be introduced and evaluated at up to 1500 m altitude.

7. Producing fish in fish ponds

Fish grown in fish ponds provides high protein food and a source of cash income. Production of carp and tilapia in fish ponds has been very successful in many highland locations in recent decades, including in the Wonenara area of Eastern Highlands, where CARE promoted them in remote villages. The fish can be fed scraps of sweet potato, other kitchen waste and greens. Provision of stock and training villagers in aquaculture techniques has the potential to increase both food supply and cash income.

In terms of these additional activities, options 1, 4 and 5 are likely to require more female labour, both in terms of planting and harvesting whilst options 2, 3 6 and 7 would be associated with male labour potentially for planting and hervesting.

Maintaining soil fertility

Maintenance of soil fertility has the potential to enhance food security as villagers, particularly adult women, do not have to work so hard to produce food and hence there is less stress on them. Soil fertility is being reduced in many parts of the highlands by increasing population and demand for food, in the absence of significant out-migration or urbanization. Techniques to increase soil fertility include:

1. Transfer of organic matter to food gardens

The most suitable organic fertilizer for sweet potato is coffee pulp as it contains small amounts of nitrogen and more potassium. It is rarely available in large volumes from village coffee plots, but it can be sourced from large coffee processing factories. Other useful sources of organic fertilizer are chicken manure and pig manure (Thiagalingam and Bourke, 1982). These should be used very sparingly on sweet potato as the relatively high nitrogen content may result in reduced tuber yield of sweet potato. They are however suitable for corn, banana, taro and vegetable crops.

2. Organic matter applied in mounds

In the western part of the central highlands, organic matter is placed on the soil surface or in mounds and covered in soil. The practice is known as composting in PNG. The primary purpose of this technique is to maintain soil fertility, although other benefits have been claimed by outsiders (Bourke, Ballard and Allen, in press). The technique is very effective in maintaining soil fertility and, where it is practiced, sweet potato and other food crops are grown for many decades in the same sites. Fresh organic material is applied at a mean rate of about 20 tonnes/ha in the 'composting zone', with a range of ca 5 to ca 40 t/ha. Experimental application of compost in locations where the technique is not traditional practiced have also increased tuber yields. It is suggested that experiments be conducted with rates of zero, 0.5, 1.0, 1.5, 2.0, 2.5 kg/m^2 (equivalent to 0, 5, 10, 15, 20 and 25 t/ha of fresh material).

3. Rotation of sweet potato with food legumes

In the northern valleys of Eastern Highlands Province, and in flatter locations in other highland provinces, sweet potato crops are grown in rotation with food legumes. Peanuts is the most important food legume, but winged bean is also used. Villagers say that planting a crop of peanuts (or winged bean) maintains the yield of sweet potato crops planted after the legume crop has been harvested. It would be useful to promote greater use of this technique in the study sites.

4. Planted casuarina trees as fallow vegetation

In several locations in Simbu, Madang and Sandaun provinces, villagers plant casuarina seedlings into sweet potato gardens towards the end of the cropping phase to enhance soil fertility and reduce the fallow period (Bourke, 2007). This is a minor practice in Eastern Highlands Province, except in the far west of the province adjacent to Simbu Province.[5] It would be worthwhile to promote greater use of this technique in the study areas. The timber from the casuarina is a valuable timber source for construction of houses and fences, as well as firewood.

5. Application of inorganic fertilizer to commercial vegetables

Villagers do not apply inorganic fertilizer (NPK) to sweet potato and other subsistence food crops. Indeed, there are dangers with applying inorganic fertilizer to sweet potato as the nitrogen sometimes results in excessive vegetative growth and reduced tuber yield. However, they commonly apply inorganic fertilizer to commercial vegetables, such as potato and cabbage. Where these are grown in a rotation with sweet potato or other food crops, there is usually a benefit to the food crop from the residual fertilizer, probably phosphate. Hence, if villagers are growing vegetables for sale and applying inorganic fertilizer, they could plant sweet

[5] *See Figure 2.10.1 in Bourke and Harwood 2009 for maps showing distribution of tree planting and legume rotation techniques.*

potato and other food crops after the commercial vegetables have been harvested. This technique is likely to be relevant to a small minority of growers only.

Options to make current agricultural systems more resilient in very wet periods where reliable medium-term weather forecasts are available

All options to make agricultural systems more resilient in very wet or very dry years when villagers do not have reliable medium-term weather forecasts outlined in the section above are relevant where weather forecasts are available. There are three more things that villagers can do to enhance resilience of their agricultural system if they were given confident advice that a very wet period was highly likely in coming months. These are:

1. Plant a greater proportion of their food gardens in well drained sites

It is important for sweet potato to be planted in well drained sites during very wet periods. This is because the staple food crop is vulnerable to excessive soil moisture, particularly in the critical weeks after planting as the potential tubers are initiated.

2. Plant sweet potato in larger mounds

Larger mounds drain the soil faster than smaller ones. So, this should increase removal of excess water from the root zone for sweet potato. Mound height in the three target areas is typically about 30 cm. Hence, villagers could make the mounds ca 40 cm or even 50 cm high to facilitate removal of excess water.

3. Dig deeper drains between planting beds

Sweet potato and other food crops are planted in long beds, separated by drains about 20-25 cm deep, in the Ifiyufa and Ontobura areas. Long drained beds are less common in the Okapa area. The third technique that may facilitate faster removal of excess soil water is to make the drains between beds deeper than normal. Hence, they could be dug 30-40 cm deep.

Options to make current agricultural systems more resilient in very dry periods where reliable medium-term weather forecasts are available

All options to make agricultural systems more resilient in very wet or very dry years when villagers do not have reliable medium-term weather forecasts outlined in the section above are relevant where weather forecasts are available. There are four more things that villagers can do to enhance resilience of their agricultural system if they were given confident advice that a very wet period was highly likely in coming months. These are:

1. Plant more food gardens on flatter land and other wetter sites

Sites which usually have a higher soil moisture content, such as in a drainage depression, are not good places to plant sweet potato under normal conditions, as excessively soil moisture can depress formation of tubers. However, during a dry period, these sites often produce high yields. So, it would be useful to plant sweet potato and other food crops in sites where soil moisture is normally high during a very dry period. In previous mild droughts in Easter Highlands, villagers who did this have been rewarded with high sweet potato yields.

2. Plant some planting material in wet sites during a drought

One issue which can slow recovery after a drought is loss of planting material. However, if villagers transplant some planting material of crops such as banana, sugarcane, taro and sweet potato to a wet site, this will maintain the planting material so that it is available when new gardens are established once rain return. The plants may not yield in these sites, but the vegetative planting material is maintained during the drought.[6]

3. Block some drains to retain runoff water

Where drains are made between planting beds, which is the technique used in the Ifiyufa and Ontobura areas, it should be possible to block off drains in a drought to retain some water from light rain showers. The water can be scooped onto plants in the bed as a form of irrigation. However, this technique would have to be used with caution as heavy rain could result in the beds being flooded or damaged by excessive water.

4. After drought breaking rain, plant sweet potato gardens on less fertile sites

After drought breaking rain in the highlands, the first planting of sweet potato commonly produces a low tuber yield (Kanua and Bang, 2001). This is because of excessive nitrogen in the soil. One technique which may reduce the impact of this phenomena would be to make the first planting of sweet potato (but not other crops) on less fertile sites. Further research is required to establish the efficiency of using such a technique.

8.6 Gaps and Strengths

In this section, we review ongoing and past initiatives on adaptation to climate variability in PNG, including programs undertaken by the National Agricultural Research Institute and the Climate Change Development Authority; and those on food storage, preservation and processing. This information has been generated via informal interviews with staff in a number of PNG institutions as well as an examination of existing literature.

This section examines the gaps and strengths of organisations in terms of their capacity to develop and deliver climate variability and risk management information. This includes, the ability of:

- National institutions to disseminate information on significant climate events and to obtain information on these from communities;
- Externally funded provincial rural development projects to undertake climate adaptation activities;
- Churches to contribute to enhanced food security;
- Community level projects by NGOs and others to deliver rural development and to address impact of climate variability; and
- National bodies and the private sector to provide appropriate farm inputs (e.g. herbicide, fertilizer, seed) to enhance long-term resilience and to assist recovery after a natural disaster.

Assessment of related ongoing and past initiatives and lessons learnt

National Agricultural Research Institute (NARI)

Following the 1997-98 drought, frosts and food shortages, the World Bank funded the PNG El Niño Emergency Drought Response project (Humphrey *et al*., 2001). This ran from 1998 to 2002. The project focused on:

[6] *An image of a family doing this is shown on page 25 of Kanua et al., 2016.*

- Selection of drought-tolerant crops and cultivars;
- Identification of better soil and water management techniques;
- Development of better soil and water management techniques;
- Development of advanced warning and contingency plans; and
- On-farm operational research.

NARI reported that drought tolerant cultivars have been developed by this project and subsequent research, however there has been little published data on the performance of these new varieties in the 2015 drought conditions. NARI has also been promoting a method of raising water from wells for irrigation 'rope and washer water pumps'. This technology has been promoted in several villages in Central and Morobe Provinces, however the rate of uptake has not been documented.

NARI also has community-level programs that disseminate technology and strengthen agricultural capacity of rural farmers by providing equipment and on-site education. An example of this work is the installation of solar irrigation pumps in Intuap, Gabensis in Morobe and Hisiu in Central Provinces. This work would serve to reduce the rainfed requirement for crops and so would help to build resilience to climate variability if there was sufficient supply for both the general village needs and crop production.

Another project is the 'Generation of Agricultural technologies to mitigate climate change imposed risks to food security in smallholder farming communities in Western Pacific Countries' implemented in Central, Eastern Highlands, Madang and Western Highlands Provinces. The project introduced new crop varieties, both for consumption and sale, introduced new livestock species, skills training in producing crops, training in processing food and making low-cost livestock feed.

To-date there has been no research or extension projects that have dealt explicitly with climate variability and effective ways to build resilience using seasonal climate information.

Climate Change and Development Authority

CCDA has identified nine priority areas for climate related work in PNG. These are: coastal flooding/sea-level rise; inland flooding; vector borne diseases; landslides; agriculture yield changes; coral reef decay; water and sanitation; cities and climate change; and climate-induced migration.

They have not conducted technical analysis or detailed planning for these priority areas to date. They are very interested in understanding more about the impacts of climate change on agricultural production and the most vulnerable locations.

The Adaptation and Projects Division has secured significant funding for activities via donor funding. The funds current cover four activities these include:

1. Adaptation to coastal flooding-related risks and hazards for North Coast and Islands Region communities;
2. Adaptation to inland flooding-related risks and hazards for river communities in East Sepik, Oro, Morobe and Madang Provinces;
3. Institutional strengthening to support climate- and disaster resilient policy frameworks;
4. Awareness raising and knowledge management.

At the time of the interview, no funds had been received by the Provincial Planning Office and no projects have been commenced. Funding is set to flow via Provincial climate change committees. At present one committee has been established in New Ireland. The next set of committees are due to be established in 2018 in five provinces, being NIP, Morobe, Oro, ENB and EHP.

Capacity of national institutions to disseminate information on disasters and to obtain information on these from communities

The National Disaster Centre (NDC) collates and analyses information received from Provincial Disaster Coordinators (PDCs), National Weather Service (NWS), other government departments and other sources. Each provincial disaster office receives information from district administrators, who in turn receive information from ward councilors. The system works better in some regions than in others e.g. Milne Bay which is well serviced. During the drought and resultant food shortages in 2015-16, routine situation reports were provided to NDC with action on this information via support the World Food Programme, Australian Department of Foreign Affairs and Trade, United Church and Adventist Church, who sent teams to the province to ascertain what assistance they could provide. Assessments and requests for support move from the local to the national level by various means. Information tends to be transmitted by mobile phone or by written letter from ward councilors to district and provincial Administrations.

Capacity constraints at each stage of the information transfer are a significant limitations on the effectiveness of these systems.

Dissemination of information on climate related issues to communities

Interviews with key stakeholders at national and sub-national levels indicated that there are a limited number of functioning early warning system in place in PNG. The interviews undertaken with key institutions indicated that the most efficient way to transmit warnings to communities was via radio, although this is dependent on the radio signal in each part of the country and the availability of radios in communities. Very few rural people have access to television or current newspapers, but there is a growing number of individuals with access mobile phones. This option does seem very promising but would require strong support from network providers like Digicel and so a user pays model would have to be developed.

Interviews were conducted with directors and senior managers at the National Weather Service (NWS), the National Broadcasting Corporation (NBC) and the National Disaster Centre (NDC) as well as some NWS provincial offices and NBC provincial radio stations.

Lack of investment and significant capacity constraints were consistently identified as major barriers to dissemination of seasonal climate information by these institutions has resulted both in a deterioration of equipment and an inability to develop human resources and procedures related to institutional linkages needed for early warning systems.

Some of the issues highlighted by respondents include:

National Disaster Centre

- Poor linkages between NDC and Provincial Disaster Coordinators, with duplication of assessments.
- Intermittent communication of disaster information between NDC and NBC.

National Weather Service

- Lack of funding to cover staff and operational costs.
- Inability of NBC to access local weather updates from the local NWS office.
- Lack of ability to provide updates on climate events as they unfold. NBC broadcasts weather reports, received from NWS, at 6.30 am and at 6.30 pm daily.

NBC radio capacity

- AM transmitters previously used by NBC throughout the country require ongoing maintenance.
- Intermittent energy supply for local transmitters.

Disaster broadcasting

- No formal disaster broadcasting framework exists. There have been attempts by some senior managers within NBC to implement disaster broadcasting procedures and policies.
- NBC has developed a draft Disaster Awareness Policy and a draft Emergency Broadcast Plan, titled National Broadcasting Commission Disaster and Emergency Broadcast policy. This has not been operationalised.

Informal networks

- There is an informal working group consisting of NBC, NDC and NWS, which is coordinated by NBC. It is unclear whether regular meetings continue to be held, but there is potential and interest by these parties to work together.
- NBC has created disaster awareness announcements and a draft disaster broadcast policy. It is waiting for NDC to provide comments or approval for this.
- Support to NBC has been provided by the Media Development Initiative, funded by DFAT.

Capacity of churches to contribute to enhanced food security

Churches in PNG have close links with communities throughout the country. Churches are often the main supplier of health and education services in communities and provide about half of all health and education services in PNG. Some of them have development arms, including the Adventist Development and Relief Agency (Adventist Church) and Caritas Australia and Caritas PNG (Catholic Church). Some churches programs are managed from Port Moresby, but most are managed at a local level. Therefore, a comprehensive review of church activities related to agriculture and climate change is difficult, as is an assessment of capacity.

This assessment highlights on some of the activities of churches in response to the 2015-16 El Niño drought in PNG. This provides an indication of the capacity and willingness of churches to increase their activities related to food security and climate resilience.

The Church Partnership Program El Niño Response Program was designed to assist the seven mainline churches of PNG to respond to food shortages caused by El Niño conditions and to leverage the networks and competencies of churches for the national response. The participating churches were: Anglican Church of PNG, Baptist Union of PNG, Catholic Church of PNG, Evangelical Lutheran Church of PNG, Seventh Day Adventist Church of PNG and United Church of PNG. The Salvation Army does not currently participate.

As well as participating in the Church Partnership Program, churches and their agencies were also engaged in assessment and relief activities during the 2015-16 food shortages and other activities related to food security. These included Caritas Australia, Adventist Development and Relief Agency, Baptist Union of PNG and United Church of PNG. All these churches and agencies are supported by overseas churches, mostly in Australia.

It is our opinion that the Church Partnership Program El Niño Response Program and their development agencies should be invited to participate in any scaling of climate resilience activities because they have well established community networks, well resourced staff and the trust of the community.

Capacity of community level projects by NGOs and others to deliver rural development and to address seasonal climate events

There are many community level projects in PNG. Some are conducted by international NGOs, some by churches and their development arms, some by major copper/gold mines and oil/gas developers and many by small Community Based Organizations.

They range in scale from very small, with a turnover of a few thousand kina a year, to quite large, with a budget of many million dollars per year. We have not conducted a comprehensive review of these projects – this would be a very large undertaking. However, we have information on some of the projects from documents given to us during the field visits and other experience. A sample of the projects being undertaken is given here to give a flavour of the focus and geographic target of some of them.

These projects provide a model of successful development in PNG. Funding provided to some of these organisations is likely to result in positive outcomes for climate adaptation activities as well as community development more broadly. We note that projects conducted by the larger NGOs often appear to achieve many of their goals.

CARE PNG

CARE works extensively in cash crop development, particularly coffee. They work closely with farmers' groups and exporters and other partners with a focus on women's empowerment. Women's empowerment activities cut across all of CARE's rural development programs.

Community Based Organisations

In recent years, many small Community Based Organisations have been formed in PNG. Some of their characteristics are:

- There is a range of issues addressed by different groups, including income generation, agricultural production, micro-credit, women's advancement and health improvement.
- They are small organizations.
- They are typically formed by a motivated individual or small group of people.
- They are self-funded or receive occasional small grants from larger NGOs, such as CARE and Oxfam.
- Funding often comes from small businesses run by the founder or others in the CDO.
- Typically, they operate in a restricted geographic area, but some work in several districts in a province.

Some examples of such small groups include:

- Food Republic, run by Prisilla Manove in Goroka. This group generates funds from production and sale of fresh food.
- Potato and sweet potato development group, run by Sam Talepakali in Enga. Sam uses some of the income from his gold smelting business (Transpacific Metals) to fund this small development CBO. They assist villagers in Enga Province with production of potato, sweet potato and other vegetables for sale.
- Vanimo Micro-credit, run by Emmanuel Peni and his business partner in Vanimo. Emmanuel and his partner conducted some business training for small businesses in Vanimo have established a micro-credit facility which funds women and men to establish small businesses in Sandaun Province. They raised capital for the micro-bank by selling a taxi business and a house and some consulting activities. They report that they achieve 100% loan repayment rate.

Fresh Produce Development Agency

FPDA has model farms that transform subsistence oriented farming to market oriented production systems. Their model 'bulb onion' farms in Simbu Province successfully cultivated, harvested, packaged and transported bulb onions before and throughout the 2015-16 drought. By taking the training from the classroom to model farms, farmers can duplicate process more effectively. FPDA has offices in Goroka, Mt Hagen, Port Moresby and Kokopo. They have a larger program in the Highlands Region, but also operate in several lowland areas.

National Agricultural Research Institute

NARI has several community level projects as part of a European Union funded agricultural technology program for smallholder farmers.

Oxfam

Oxfam is conducting a four-year program which uses a series of interconnected livelihood innovations and market-based development activities to support private enterprise and community organisations to increase the incomes and well-being for rural farming families. The focus in the highlands, particularly in Eastern Highlands, Simbu and Jiwaka provinces.

Red Cross

Red Cross supports a food processing initiative for a group of women in Hagen, Western Highlands. Women produce roasted cassava, sundried ginger, sundried turmeric, peanut butter, curry leaves, strawberry jam, sundried rosemary, chilli and *marita*, and can make a profit by selling produce at markets. This small group of women have their workshop open to visitors, and there are currently over 200 local men and women who watch and learn the techniques and try it at home.

World Vision

World Vision International (WVI) has a community-level focus for its program as demonstrated during the 2015 drought. Their focus is on communities as the first responders to an emergency. They consider the capacity of communities and then devise appropriate training activities.

Capacity of national bodies and others to provide appropriate planting material

The introduction of more flexible farming systems that respond to unfolding seasonal climate conditions will require rapid access to planting material and other farming inputs. For this reason we have examined the ability of national bodies, including NARI, FPDA and DAL, commercial bodies, NGOs and the informal sector to provide appropriate planting material.

Sources of planting material in PNG

Almost all the staple food crops are propagated by vegetative material, not by seed, including sweet potato, banana, sago, taro, yam and cassava. A number of vegetables are seed propagated, including corn, pumpkin, beans and cucumber, but most are propagated by cuttings rather than by seed. This presents challenges for those seeking to provide planting material, including the high disease load that often occurs when crops are grown under intensive conditions, for example, on an agricultural research station.

The main sources of planting material for PNG food producers are:

- **Villagers' own resources:** Most rural villagers obtain most of their planting material from their own food gardens or that of neighbours, family and friends. When climate extremes damage their gardens, as occurs during drought, frosts and periods of very high rainfall, they are commonly short of planting material.
- **Public sector:** The National Agricultural Research Institute (NARI), Fresh Produce Development agency (FPDA) and national Department of Agriculture and Livestock (DAL) have some capacity to supply planting material of some food crops.

9 Impacts

9.1 Scientific impacts

The project has generated new knowledge within a number of scientific domains, with significant potential for impact on future research. The development of a Social Network Analysis has never been applied to examine how information flows through communities. This provides key insights into how SCF information is exchanged within and between communities, issues of trusted information sources, gender differentiation and identification of "gate keepers' and facilitators of knowledge. This analysis was undertaken at individual village levels as well as aggregated across the three villages to provide an assessment of commonalities. This is important is addressing the challenges of scaling the extension of SCF information. The results from this analysis also provide important insights into both common and disparate information needs for communities with regard to climate information. The analysis of the survey information will be incorporated into a journal publication (notionally Environmental Science and Policy – Davila, Crimp, Sweaney, and Sloan) and the approach has been presented at two scientific conferences by Federico Davila (Australasian Aid Conference 12-14 February 2018) and Steven Crimp (Australian Defence Roundtable, 10 November 2017).

9.2 Capacity impacts

In terms of capacity impacts, this SRA has had small positive impacts on NARI staff and the case study regions. In terms of staff impacts, the training provided with regards to the survey design and implementation has served to enhance the skill of five staff in this research field. The staff had indicated that this was the first time they had received training of this sort and indicated that the survey design and implementation skills would complement existing projects.

The installation of the three weather stations now provides NARI with the tools to collect long-term weather information for these case study villages. Until the installation of these stations only one operational weather station existed in the case study region i.e. Aiyura. The digital interface provided with the weather stations and the 48hr forecast capability of the loggers provides an important resource to the village in terms of more accurate weather forecasts.

9.3 Community impacts

This project was not specifically designed to introduce new farming methods to farming communities but was a scoping study to determine the seasonal climate information needs of the communities and the capacity to serve these needs within PNG. For this reason determination of community impacts is largely prospective.

9.3.1 Economic impacts

Understanding the response of these important staples to climate variability and other environmental conditions and applying this knowledge to enhance on-farm management will have important positive benefits for farm livelihoods. For farming households, improved cropping, water and nutrient management techniques will increase net household income through increased yields and/or a reduction in production costs. This information, when effectively extended, will lead to increased crop resilience and rural livelihoods.

Taro production in the South Pacific region averaged 360,000 tonnes per year for the nineteen years ending 2009, with PNG, Solomon Islands and Fiji the largest producers. The annual production of cassava was estimated to average 290,000 tonnes per year for the same period, with PNG, Tonga and Fiji the largest producers.

While the full range of effects of climate variability on the production levels of these crops are unknown, it is clear that climate variability and pest and disease pressures could have a significant impact on taro and cassava yield and quality. Even just a 10% climate-induced reduction in total output (as seen in some instances from the country statistics), is equivalent to A$30 million annual loss in the total value of taro and a A$16 million annual loss in the case of cassava. (note that a 10% production loss due to extreme weather events and new pest and disease challenges is a subjective measure, but it is conservative when compared with losses of up to 80% due to historical climate extreme events). Providing farmers with strategies to deal with climate variability is likely to reduce the size and impact of these losses. Again, assuming conservative outcomes (that is a 5% adoption rate and that only half of the climate change effects can be offset), the expected benefits of this research is A$0.6 million annually. Sensitivity analysis shows that even if only 25% of the climate change effects can be addressed the total annual benefit is still A$0.2 million annually.

Within the reported range of climate-related losses of between 10 and 70% of the total crop, a higher estimate of losses (e.g. 30%), seems plausible for exports (given that the export market demands large, blemish-free corms). On this basis, approximately US$12 million of export earnings could be lost each year. By developing more resilient cropping practises that reduced these losses (e.g. to only 10%) and with uptake again estimated at 15%, a saving of $600,000 p.a. in the export sector might be possible.

9.3.2 Social impacts

Presenting options for a more resilient cropping system in these regions has enabled the research team and local agricultural extension staff to work with local farming communities to explore options to improve and enhance current production. Enabling such interactions has the potential to have significant social and community impact. Without this added support, smallholder livelihood strategies will inevitably become even more constrained than at present, leading to both personal and communally-shared hardship and potential social dislocation as communities stagnate or lose further members to migration. Protecting against this source of adverse social impact is partially addressed by increasing productivity.

9.3.3 Environmental impacts

By developing a modelling framework that allows a range of management options to be explored this project has identified options that deliver both positive and negative environmental impacts. Better matching of cropping systems to current and near future climatic conditions may result in changes in water and nutrient use, possibly improving the environmental footprint of cropping system. However given the subsistence nature of these cropping systems (i.e. minimal inputs), these gains are likely to be very small. Intensification of crop production as a consequence of positive simulation information could potentially lead to soil fertility losses and erosion. However increased local yields may reduce other negative environmental impacts associated with food importation.

9.4 Communication and dissemination activities

The communication of outputs from this project have occurred at a number of levels. These include:

- interaction (via workshops) with local extension staff and farmers, to discuss field demonstration trials and use the model in a participatory training mode (as above) as a tool to empower choice among a range of varieties and other management options (Steven Crimp and Tom Sloan, 27th to 29th April 2017 in Okapa, Ontabura and Ifiyfa);
- training opportunities with local extension staff in order to allow staff to apply the model in further extension strategies (Steven Crimp and Tom Sloan, 26th to 27th April 2017 in Ayura);

- presentations to donor organisations (similar approach - scientific evidence and scenario-based modelling) to advocate further investment in specific research areas or extension strategies (Steven Crimp, DFAT Agriculture, 7 November 2017 and Defence Roundtable, 10 November 2017).; and participation in international conferences to increase scientific impacts among peer group of researchers and obtain feedback to the research effort (Tom Sloan, Australasian Aid Conference 12-14 February 2018).

Dissemination of scientific knowledge generated by the project will occur through the production of scientific journal paper.

10 Conclusions and recommendations

In the sections that follow we present the higher level conclusions of the research outputs and attempt to place these findings in the context of adaptation to climate variability.

10.1 Conclusions

The primary aim of this project is to examine ways to improve PNG highlands food security in the face of climate variability and change through specific focus on staple food production systems. A secondary aim of this project is to support the enhancement of existing agricultural production through the provision of seasonal climate information relevant to respond to unfolding seasonal environmental conditions.

The SRA project strategy involves using social network analysis surveys, expert knowledge, spatial mapping and statistical analysis for this scoping study. The data generated as part of the SRA has been used to identify how climate information is, and could be, disseminated effectively amongst rural communities and government agencies; the form the seasonal climate information would need to take in order to be effectively understood and actioned as well as the possible farming options to pursue during different season types.

The SRA has seven clear objectives these are:

- Building capability of PNG research agencies and rural communities to link to regional climate forecasting capability through examination and characterisation of formal and informal knowledge networks.
- Based on the knowledge network analysis, identify new operational seasonal climate forecast knowledge products from around the world, that would have relevance to PNG in helping communities and agencies, and examine how these could be hosted by the PNG weather service to provide information relevant to agriculture.
- For three case study sites, establish weather stations to monitor temperature, rainfall and solar radiation and work with PNG Weather Services, NARI and community leaders to effectively manage and disseminate the climate information in formats usable by the community. These will become part of the PNG Weather Services NWS weather station network in order to improve the observation of weather and climate trends in the Eastern Highlands.
- Understanding how agricultural vulnerability has changed by examining and mapping changes in historical rainfall and temperature.
- Developing climate smart response options for farming communities in the face of below “normal” (e.g. El Niño) and above “normal” (e.g. La Niña) seasonal rainfall conditions, based on expert knowledge, previous research activities and traditional ecological knowledge (e.g. Bena coping strategies).
- Determination of information/technology/asset gaps in the dominant farming systems of the case study districts and present a gap analysis to ACIAR and NARI.
- Drafting a set of recommendations on research for development questions/topics relevant for climate smart agriculture in PNG.

In terms of the Social Network Analysis (SNA) the survey showed that the overall network behaviour showed that church, community, and family were the most trusted and most central groups in across all villages. These three groups also created cliques (sub-networks), meaning that they interact with each other frequently. Government was a highly trusted source reaching the central groups, however they were only disseminators of knowledge, not recipients. This raises questions regarding the extent to which government is able to access and receive feedback from the communities and adjust their information dissemination strategies.

Farmer-centric analysis shows that farmers are highly trusting of most major groups: community, church, and family. Farmers also showed high levels of trust in NARI extension officers. Overall, farmers were the recipients rather than disseminators of knowledge. This provides a range of opportunities to reach farmers via different major groups in the community. Care needs to be taken to reduce the chances of farmers receiving conflicting SCF information from different sources, as they might not know who to trust if information is not consistent.

There are strong sub-group connections between church, community, family, and Wantok. This means that these cliques and strong connections can act as catalysts of information dissemination. They can be targeted to disseminate information to smaller, more distant groups, such as youth groups and women's groups.

Drought early warning systems were consistently identified as the most important SCF information needed. Rainfall and temperature forecasts were the next most important types of information. Similar to the trust maps, the overall network shows that family, community, and church groups were the most important sources for obtaining different SCF information. Farmers are not perceived as important for disseminating SCF, confirming that they are passive knowledge recipients in these networks. Some differences between villages were noted. For example, Okapa reflects the common finding that family, community, and church are highly influential and exchange different types of knowledge. Outlier groups are farmer organisations, natural sources (learning from observation) and agricultural extension officers. However, the findings for Ontobura were contrasting. Family, community, and church are perceived as most useful sources only for weekly temperature, drought early warning information, and rainfall (daily and seasonal forecast). Different types of information (daily temperature, monthly and weekly rainfall) seems to be best sourced from government agencies, media, farmer organisations, and agriculture extension officers.

There were no major differences between males and females regarding overall trust. Both sexes were found to be highly trusting of the central groups of church, family, and community. Males placed farmers and NARI as central sources of obtaining SCF information, whereas females saw family and community as more central information sources. The survey as a method is unable to determine how men and women use SCF to inform farming practices. Qualitative methods can fill this gap.

In terms of the placement of the weather stations and development of software to analyse the data from the stations, the weather stations were installed but have only been collecting data for a period of five months. Unfortunately the dataset was too short to test the analysis software and so long-term records from Aiyura were used to test the utility of the software. The analysis software was able to quickly analyse the trends for 57 different derived temperature and rainfall variables and highlight those that were statistically significant. Future version of this software will include an automated approach to graphing these trends.

In terms of the spatial mapping of rainfall and temperature trends for the whole of PNG, the statistical approach developed allowed the extrapolation of sparse spatial and temporal records to produce the maps. The results from this analysis show considerably warmer conditions over the western half of the country and drier conditions in the south west and wetter conditions over much of the rest of the country. This mapping does highlight regions where the rate of climate change is happening more rapidly than others but also shows where seasonal variation has increased.

The review of resilient farming systems served to identify a series of possible farming options to cope with both extreme dry and extreme wet conditions. These adaptation options will be tested during the next phase of this project.

The scoping study has served to identify a number of gaps and strengths of existing institutions in the delivery of seasonal climate information and the sections that follows presents a series of recommendations that serve to improve capacity and service the community with regard to seasonal climate information.

10.2 Recommendations

The findings from this research show some major themes important for future surveys and disseminating SCF to end users. Across the different maps, it is evident that the community/church/family/Wantok individual groups and cliques are important sources of information, and are highly trusted. All groups were consistently central in all maps, and acted as avenues to reach smaller community groups, such as farmers or women's groups. This overall behaviour across all villages provides an overview of possible groups to target for SCF information. If the project is to have sustained uptake of SCF, then future surveys will need to look at ranking how SCF is used by the different groups. This would enable the research team to link the SCF to farming practices.

Drought early warning systems, temperature, and rain forecasts were the most important types of information. Multiple sources were seen as important for disseminating information. This provides a broad opportunity for future SCF dissemination strategies that target core trusted groups (family, community, church) and enable them to reach other groups.

There needs to be important consideration into the impact pathway for ensuring sustained adoption of SCF knowledge products. The survey revealed that farmers are passive recipients of information. Literature shows that for SCF to have impact it needs to be relevant to the end users and has to be consistently presented in an appropriate format. Quantitative surveys are unable to show how information is used to inform different farming practices across different commodities. Embedding a series of monitoring and qualitative research components to future SCF projects would allow research teams to understand how technical outputs can be used by farmers to adapt to climate change.

The design, conduct, and findings from this SNA present lessons for up-scaling to other countries. These lessons covering training, conduct, and broader SCF research recommendations are provided below.

Training lessons: use the lessons identified in the Training Report to improve training design, translation, delivery, and contingency plans.

Broader SCF research and design of impact:

- Design an impact pathway of how technical SCF information will reach end-users, and how this information can be adopted long term.
- Capture as many baselines on commodity production economics, natural resource issues, and the knowledge system of target villages when projects begin. Baselines will allow team monitor evaluate and learn as research findings emerge and are adopted by end users.
- Aim to understand if there is conflicting information on SCF for food production being delivered by end-users (farmers).
- Work with key 'boundary and knowledge brokering' cliques that are highly trusted in the villages to disseminate information. This can enhance legitimacy of knowledge products.

Interviews with key stakeholders at national and sub-national levels indicated that there a limited number of functioning early warning system in place in PNG. The interviews undertaken with key institutions indicated that the most efficient way to transmit warnings to communities was via radio, although this is dependent on the radio signal in each part of the country and the availability of radios in communities. Very few rural people have access to television or current newspapers, but there is a growing number of individuals with access mobile phones. This option does seem very promising but would require strong support from network providers like Digicel and so a user pays model would have to be developed.

Lack of investment and significant capacity constraints was consistently identified as major barrier to dissemination of seasonal climate information by institutions working with rural communities and has resulted both in a deterioration of equipment and an inability to develop human resources and procedures related to institutional linkages needed for early warning systems.

This literature review highlights a number of ongoing knowledge gaps and improvements that could be made to improve SCF uptake and the range of knowledge products that incorporate seasonal climate conditions. This review and results from the surveys undertaken in this study highlight that both farmers and R&D staff are familiar with the historic climate variability of their region and where to source weather and climate information from, but are less knowledgeable with regards to the drivers of climate variability, the level of regional and temporal SCF skill/accuracy and how the SCF could potentially be used to improve farm profitability, value chain management or policy development and implementation. The review and survey revealed that the most significant barriers to use of SCF remain:

- perceived lack of local or regional relevance;
- perceived lack of sufficient lead time;
- perceived lack of skill/accuracy during periods when critical farm level decisions and period of time during which the SCF has perceived skill;
- context relevant knowledge products;
- lack of formal training or capacity building, and
- perceived lack of application to understanding how SCF's translate to measurable improvements in farm profitability.

In recent years dynamically-based atmospheric general circulation models (AGCMs) have become a mainstream tool in seasonal climate forecasting, with a de-emphasis on existing statistical forecast systems. This is largely due to perceived limitations in performance of statistical systems in capturing the changing teleconnections in response to anthropogenic climate change.

However, due to capacity constraints, we recommend that only two of the SCF products identified in the review are relevant for further application in PNG. The first is SCOPIC developed by the Australian Bureau of Meteorology and produced by the PNG NWS and the second is the APCC Climate Information Tool Kit (CLIK1.0). Both forecast products are capable of being regionalised using statistical downscaling methods. The SCOPIC forecast product, if more extensively applied to local regions, might represent the preferred forecast product given its ease of use and the familiarity of the PNG NWS with this product. The downside of this approach is that it is not a multi-model ensemble approach and so the prospects of improving the SCF skill are limited.

In terms of farming systems options we identify three broad areas of activity that would help to build resilience into existing farming systems. These include:

Greater access to cash income - Access to cash provides one of the best safety nets for rural villagers when subsistence food production is inadequate, for whatever reason. During food shortages caused by drought and frost in the highlands over the past 50 years, villagers who can access cash have been able to 'buy their way out of trouble', that is, to purchase food when their sweet potato and other crops have failed. Those who could not access cash suffered the most. Helping villagers increase their access to cash is not the focus of this study.

Broader range of staple food crops and cultivars - Production of a greater range of staple food crops or cultivars of existing food crops to supplement the staple food, sweet potato, would increase resilience by reducing the dependence on a single staple food.

Maintaining soil fertility - Maintenance of soil fertility has the potential to enhance food security as villagers, particularly adult women, do not have to work as hard to produce food and hence there is less stress on them. Soil fertility is being reduced in many parts of the highlands by increasing population and demand for food, in the absence of significant out-migration or urbanization.

Some other recommended actions that could help local rural communities improve the resilience of their farming systems include:

- Supporting cash generating activities, such as providing seed for cabbage, broccoli, sweet potato and carrots.
- Support the improved processing of staples, such as cassava and corn flour. Current losses resulting from poor processing and poor storage could be significantly reduced through support and improved infrastructure.

- Supporting an enhanced Regional Food Storage program, such as the one run by the Fresh Produce Development Agency (FPDA).
- Supporting the improvement of local market facilities so that cash crops can be more effectively processed, sold and purchased.
- Supporting enhanced dryland rice production given only 10% of the rice consumed in this region is grown locally. Local milling services for farmers already exist and so simple value adding could be achieved with relatively small investment.
- Potentially working with local farmers to examine alternative markets for their crops through co-operatives or helping to broker external contracts.
- Provincial governments, DAL and DPI, need finance officers or other administrators who can assist to obtain grants from NGOs, donors or UN organisations. They have technical expertise, but not administrative expertise.

There are numerous small church activities in Eastern Highlands Province and there is an opportunity for churches to be engaged to provide services. Many NGOs have a presence in Eastern Highlands Province, including Red Cross, CARE and Oxfam. The provincial capital, Goroka, is also home to many institutions including Fresh Produce Development Agency, Coffee Industry Corporation and the national Department of Agriculture and Livestock Highlands Regional office.

Given the lack of scalable infrastructure to deliver Seasonal Climate Forecasts in PNG, as well as the need to have tailored and context relevant information for rural communities we believe that the development of community based climate information centres is the more effective approach to improving resilience to climate variability.

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12 Appendixes

12.1 Appendix A - survey methodology and limitations

There are two major types of SNAs: ego-centric and socio-centric. This survey collected individual data, which was then organised into major groups. The analysis was socio-centric – we were looking for the relational ties between a bounded community (i.e. each village). Ego-centric analysis was conducted for farmers only, where we looked at who farmers receive and share information with, and the level to trust associated with sources of information.

To allow for robust analysis, and also the production of visually aesthetic maps, multiple responses had to be aggregated into meta-groups. The overview of what forms part of each group is in Table 15.1.1.

To examine information exchanges, we looked at the links between information flow and frequency questions:

- Who or what are the main sources of information about weather and forecasts of weather?
- To whom do you give information and advice on weather and forecasts of weather?
- In your opinion, what are the most trustworthy sources of information about weather and forecasts of weather?
- From those sources of information, can you rank them from highest (1) to lowest (7) in terms of how much you trust them?

We built a matrix from this data that examined frequency of links between sources of information and who information was passed to. For level of trust in sources of information, all responses were averaged for each organisation so as to obtain an overall value of "trust".

We then mapped this matrix of information exchange using the package 'igraph' in R (Csardi and Nepusz, 2006). These maps were used to develop knowledge networks at various levels (all surveys, villages, gender etc). Only directional ties were mapped, and loops (where information was exchanged within one group) were excluded.

To examine links between important types of information and important sources of information, we examined responses to two questions:

- In your opinion, what are the most important types of weather and weather forecasts information?
- In your opinion, what is the most useful source of information about weather and forecasts of weather for your primary occupation?

This data was arranged in to a matrix that examined frequency of organisations and types of information being mentioned together. Respondents were not asked directly where they wanted to/did receive certain types of information, so rather this analysis examined casual relationships between important information and sources. As a result of these casual relationships, the map was non-directional.

Table 15.1.1. Overview of sub-groups included in meta-groups for analysis

Government	Church	Community	Natural Sources	Agricultural Extension Officers	Family	Media	Others/Excluded
Government agencies	Church groups	Community elders	Traditional knowledge	NARI	Family	Media	CARE Organisation
DPI Officers	Pastor	School teachers	The weather	Ag Extension Officers	Family group	Radio	
DPI	Church (youth group)	From people	Myself	The new agricultural extension officers	Family knowledge	Television	
Government Officers	Church council	Co-operatives	From nature				
Law and order section	Church women's group	Local associations (not specified as farm)	Natural methods				
		Particular community members	Traditional predictions				
		Children's foundation					
		Class peers					
		Community groups					
		Community work					
		Councilors					
		Peer group					
		Small children					
		Sports groups					
		Friends					

The major lessons from the Training Report on future training and survey design are as follows:

Hybrid approach training and data collection

While the hybrid approach proposed at the design phase did not occur, the benefits it is likely to provide should be integrated into a scaled up version of this SRA. Such an approach would likely involve the co-delivery of training between the survey design team (Sustineo) and the local research team (APR), with the NARI staff embedded within the data collection team. This could provide a range of benefits that include reiteration of training outcomes during field data collection, potential for higher numbers of collected surveys, and greater confidence in the quality assurance and control mechanisms in place.

There could be the potential to open leadership and supervision opportunities for high-performing or high-potential NARI staff. For example, if the next phase includes three different regions there could be a NARI focal point who is involved across each region, as both a point of continuity. There could be scaled up engagement with NARI, potentially through such a key focal point, in the analysis of the data to identify how those findings are more broadly relevant within NARI.

The specifics of how this approach would be operationalised would need to be discussed between the different organisations to ensure roles and responsibilities are clear. This could take the form of a project design workshop, prior to the conduct of training activities, with all key organisations in attendance.

Approach to survey development, piloting and translation

It was clear from the pilot that the approach to translating the survey was not sufficient. The NARI staff noted that survey translations are a challenge, given the diversity of regional dialects within Papua New Guinea. In a scaled up version of the project, more time should be factored into to the design, piloting and translation phase. This would be to address both the translation issues, as well as some of the other mechanical issues which we picked up in the pilot (as noted in the section above).

If the project were to be scaled up, we would propose an approach that broadly included following stages be implemented. As noted above, these would need to be refined on the scope of the scaled-up project.

Stage 1 – Design of a survey in English. This would be led by a survey design team in collaboration with other project partners. We propose that this would include at least the survey design team, CSIRO and NARI. The purpose of including NARI would be to engage them at an earlier point in understanding the intent behind the survey, drawing on their local expertise in helping to shape it to be of greatest us, and refining both the questions and possible response options.

Stage 2 – Translation into Tok Pisin. This would be led by the local research partner or NARI (depending on the structure of the next phase). This would then be reviewed by an individual or organisation not involved in the initial translation. While this could include a reverse translation phase, where an individual or organisation not involved in the conduct of the initial process translates it back into English, given the variability in dialect across regions, it may not be essential given the proposal in Stage 4 to take this version be taken as the 'baseline' translation to be refined in each regional location.

Stage 3 – Pre-test the survey. This would be led by the local research partner or NARI staff involved in this SRA (depending on the structure of the next phase). This would be to initially identify any significant issues with mechanisms of the survey conduct. Reporting back on this would shape revising the survey tool prior to the training and piloting.

Stage 4 – Regional translation, training, pilot and revision. This stage would be very much influenced by the structure of the next phase. It would mostly likely be led by the survey design team, and include the local research partner, CSIRO and NARI. Initially, this would serve to revise the Tok Pisin translation to be regionally relevant, such as through a workshop with local NARI staff. Once this has been established, training would be conducted with the nominated NARI staff and those of the local research partner. This would lead into a selected piloting of the survey, with NARI staff embedded in the local research team. A debrief at the end of this process would lead into the revision and refinement of the survey tool. This would be undertaken prior to the team going out into the field for data collection.

Ideally, this stage would be replicated in each of the regional locations that the survey was to be conducted. Noting that the cost implications of this would increase with the more locations that are selected, this would likely be best suited if the next phase focused on a small number of different regions. This would be led

Stage 5 – Data collection. If part of a hybrid approach, this would be led by the local research organisation and NARI.

Structure of training

The training activity should be conducted with participants who do not have any other active work responsibilities for those designated periods. In this next phase, achieving this would be important for ensuring consistent training outcomes are achieving across all training participants. It would also be beneficial to isolate the conduct of training and survey piloting from other activities so that all training participants have their full attention on the survey task at hand. This is not necessarily something that in practice is easily achieved, but should be aimed for insofar as possible.

Contingency

For the up-scaled version, a greater degree of contingency could be built in to the scheduling of country visits.

12.2 Appendix B – other network maps on request

Other network maps if required

12.3 Appendix C – summary of survey training

CSIRO-Sustineo training with NARI recap

This document provides an outline of the key points to remember from the CSIRO-Sustineo run survey training with NARI. The important points to remember include consistency, confidentiality and impartiality. In terms of consistency, we want to make sure that we are consistent in the way that the survey is conducted individually, within the NARI team and between the NARI team and Anglo-Pacific Research (APR) team. In terms of confidentiality, we want to make sure that a response cannot be connected to the participant. In terms of impartiality, we want to represent the thoughts, opinions and experiences of each individual participant as truthfully as possible.

Contact Sheet

- Ensure the information is consistent between the Contact Sheet and the Survey Form. Double-check this at the end of the interview.
- On the Contact Sheet 'community' refers to the 'site' that data is being collected from. Make sure this matches the site you are at and is consistent with the one noted on the Survey Form.
- Store the Contact Sheet separately from the Survey Forms to make sure the identity of the participant is kept confidential. Protecting the identify of participants by making sure others cannot identify their answers is important.

Approaching participants

- Remember, the way that participants were notified of the survey teams attendance and asked to attend a location during the training and pilotias different to how it should be done.
- When collecting data, remember that we want to get a random selection of people to make sure that we have a fair representation of the community. From the central site (for example, Ifiyufa) go as a group to a location where people will be (for example, a main road, a market, church, etc). At each location,

approach individual participants and invite them to participate in the survey. Remember to let the participants know who you are, what you are doing and what the project is about. After completing a few (about two) interviews each, move onto the next location. Remember, do not invite the farmer groups to come and participate, as we want a random selection of participants from the community.

- We want to get an even number of female and male participants across different age groups (18-25; 26-40; 41+). It will be important that during and at the end of each day, you work as a team to make sure there is an even number of interviews being conduct across these gender and age groups.

Consistency

- Make sure you read each question, in full, exactly how it is written in Tok Pisin on the Survey Form. This is important in making sure that the data we collect is consistent. If it is not, then we will not be able to compare the data and this will undermine the analysis.
- Avoid giving examples or too much explanation of the question. Remember, the examples that are written on the Survey Form under each question are to help you categorise the participant's response. To be consistent with our approach, make sure you do not give examples to participants as this will influence their response and undermine the strength of the data you collect.

Conduct of interviews

- Record the response the participants give you and do not make assumptions about their level of knowledge on certain issues. Although you know a lot about this subject matter, your role is to be impartial. It is important we get the thoughts, opinions and experiences of each individual participant.
- Remember to ask the question in full, including the "In your opinion…" part. This will help maintain consistency across all the surveys that are conducted. This also includes, as noted above, making sure you do not give examples.
- Remember to emphasise that there is no right or wrong answer. Their thoughts, opinions and experiences are valuable to the project.
- Make sure you check with the participant whether they have been interviewed before on this topic by a survey team (APR). If so, the move onto the next participant.

Recording data

- Make sure that enough detailed information is record from participants for each question. For example, if someone says they are in a 'community group', you should find out what sort of community group they are in.
- We are confident in your ability to interpret participant responses to questions, however make sure you still write down 'notes' on what they said. This will help us to make sure that we all categorise responses in a consistent way.
- Make sure that at the end of each day, you report and record the number of interviews you have conducted (including their age and gender) with your survey supervisor. This is important in making sure we have a good representation of different groups in each community. If the team has not got enough of a particular group (for example, 41+ year old females), then make sure they are the focus of the next group of surveys at the site.
- If something happens during the course of the interview that you think could influence the participant's responses (for example, someone starts listening in), make a note of this. Make sure you do this after the interview and away from the participant.

Quality assurance and supervision

- In the field, the survey supervisor will be responsible for coordinating the survey team, including identifying the locations to visit. The survey supervisor will also be responsible for double checking surveys in the field to make sure that the responses are clear and consistent between the different survey team

members. During the data collection, the field supervisor should keep track on the number of surveys conducted across gender and age, and make sure the team is targeting groups where numbers of low.
- At the end of each day, the survey supervisor will be responsible to collating and summarising the total surveys conducted in the day by the enumerator team. They are also responsible for noting down a brief summary of what locations were visited and any other events that occurred which could have influenced the collection of data.

Location of interviews

Overall, there are 110 interviews that NARI staff will be responsible for collecting. These will be across three different sites. The table below shows how many surveys have already been collected at each site, how many we need at a minimum to do the analysis we need to do, and how many NARI are contributing.

Site	**APR surveys collected**	**Minimum need for analysis**	**NARI surveys required**
Ifiyufa	40	110	**70**
Okapa Station	90	110	**20**
Obura Station / (Ontobura)	90	110	**20**
Total	220	330	**110**

12.4 Appendix D – summary of survey data:

Data entry guidance note

This document provides guidance on the entry of paper based survey data into the digital Excel form. An important note is to record, within the Excel document, all the information that is provided in the survey form. Doing so provides us with the best means of being confident in the consistency between the Anglo Pacific Research and NARI surveys.

Data entry

The 'NARI Data Entry Template' document is set out in the same structure as the paper survey, starting with the 'Survey Information' section and sequentially moving through each page of the survey through to 'Part Six: General Media Access'.

The following section outlines a few points to remember when entering the survey data into the Excel form. These include:

- Using the 'note' section for each question to give extra information
- Entering multiple responses to a question
- Providing extra information when it doesn't pertain to a particular question

For consistency, please use 24:00 hour time when recording the start and finish times for interviews.

Certain questions have the option of providing a 'Note'. For example, 'What is your age? (Question 1) as an option for 'Note question 1'. A note will be made in this column if the participant did not recall their age, and you then made a judgement of their age based on your own observation. If there is no relevant 'note' written on the survey form, then leave the Excel cell blank. In the Excel sheet, it would look like the below picture:

Survey page 2	
What is your age?	**Note question 1**
41+	Observed (participant does not know age)
41+	

Throughout the survey, there are a number of questions which ask the interview to record a 'note' to provide more detail participant's answer. For example Question 8 asks *'In your opinion, what are the most important types of weather and weather forecasts information?'* In response, the participant might answer the question (for example, daily temperature) but will provide further details as well. **It is important to make sure you enter the participant's response (i.e. daily temperature) and the 'note' separate cells.** In the Excel sheet, it would look like the below picture:

Survey page 7	
In your opinion, what are the most important types of weather and weather forecasts information?	**Note question 16**
Daily tempature	She assess daily cloud cover and tempature so she thinks
Daily rainfall	
Daily sunshine	He interprets the local weather pattern
Daily rainfall	

If there are multiple responses for a question, list each of these under each other. For example, Question 9 asks '*What types of information about weather and forecasts of weather influence your primary occupation?*' If a participant answers 'daily rainfall, weekly rainfall, daily temperature and weekly temperature', then each response should be entered into its own cell in the column of the question they are responding to. In the Excel sheet, it would look like the below picture:

Survey page 4	
9	10
What types of information about weather and forecasts of weather influence your primary occupation?	**How important are these different types of weather information for your primary occupation?**
Daily rainfall	5
Weekly rainfall	5
Daily temperature	5
Weekly tempature	5

In the above example, the participant's response to question 10 should align with the response to 9.

The same principle applies for other questions where there may be multiple responses from participants. For example, in Question 17 ('*In your opinion, what is the most useful source of information about weather and forecasts of weather for your primary occupation?*') if the participant identifies multiple sources, enter each separate source into its own vertical cell. For Question 18 (*From those sources of information, can you rank them from highest (1) to lowest (7) in terms of their usefulness to your primary occupation?*), the rank between those different sources should be listed next to the relevant response to Question 17. The picture below shows how this would look.

Survey page 7	
17	18
In your opinion, what is the most useful source of information about weather and forecasts of weather for your primary occupation?	**From those sources of information, can you rank them from highest (1) to lowest (7)**
Government agencies (NARI)	1
Media (radio)	3
Wontok	2

If there is a comment listed on the survey form but there is not an appropriate space in the excel sheet to 'note' it, enter that information in Column BD of the excel sheet. This is at the end of the Excel form, under the title of '*List any notes from other questions in the survey - list both the question number and comment*'.

Overall, the key points to remember are:

- Enter the survey data into the Excel form in the exact way it has been recorded on paper
- Make sure you add the 'notes' that interviewers have made around the questions
- If you are unsure of a particular response, ask the original interviewer for clarification
- If you are still unsure, ask the survey entry supervisor and make a note of your decision. This is to help ensure consistency throughout data entry.

Quality assurance and consistency check

Ensuring accuracy and consistency are important in having confidence in the quality of the data we collect. Having the appropriate processes for data quality is an important part of working in a team on this project. There are two key components of this for data entry.

First, the surveying process and data entry process should be done by different people. So, data should be entered from survey forms that you did not complete yourself. By entering data that was collected by your colleagues, this increases the chances of identifying inconsistencies, if any, among the team. If you are unsure of something you are entering, ask you colleague for clarification.

Second, some surveys will be reviewed by a supervisor. This review processes is aimed at ensuring accuracy between what was written on the paper survey and what was entered into the Excel template. We expect that a supervisor will review at least 20% of surveys throughout the data entry process. This means that, through the completion of the survey the supervisor will review 2 out of every 10 surveys. This will be undertaken for the surveys entered by each enumerator, and also for each of the three sites.

12.5 Appendix E - survey question and translation issues

Question	**Response option**	**Issue identified:**
8. [Ol weather na toksave bilong weather save mekim kamap wok yu save mekim?] [*Does weather ~~and forecasts of weather~~ influence what you do in your primary occupation?]*	**Selection option (Circle)**	The English version of the question is not phrased appropriately. The interest at this point is in 'weather' rather than 'forecasts of weather'
16. [Long tingting bilong yu, wanem em ol bikpela kain ol weather na luksave bilong weather toksave?] [*In your opinion, what are the most <u>important types</u> of weather and weather forecast information?*]	**Free-response with sub-categories (circle issues mentioned)**	The Tok Pisin translation is too broad.
18. [Long ol dispela hap bilong kisim toksave, inap yu makim we antap (1) igo tamblo (7) long wanem gutpela sapot na halivim long wok bilong yu?] *[From those sources <u>of information,</u> can you rank them from highest (1) to lowest (7) in terms of their <u>usefulness to your primary occupation</u>?]*	**Rank the sources from highest (1) to lowest (7). If the participant gives less than 7 responses, only rank those which they have provided.**	The Tok Pisin translation is not structured in an appropriate way. It is confusing.
19. [Long tingting bilong yu, wanem gutpela wei we yu ken kisim toksave long weather na luksave bilong weather?] [*In your opinion, what is the best way for you to <u>receive information</u> in relation to weather and weather forecast information?*]	**Free-response with sub-categories (circle issues mentioned)**	The Tok Pisin translation is not phrased appropriately (i.e. in relation to 'the <u>best</u> way for you…'). Question 19 very similar in the Tok Pisin translation to Question 17, although in English the distinction is clear.

20. [Long tingting bilong yu, wanem em trupela ol hap bilong kisim toksave long weather na luksave bilong weather?] *[In your opinion, what are the most trustworthy sources of information about weather and forecasts of weather?]*	**Write the sources of information in the boxes.**	The Tok Pisin version translates as 'receives' whereas the English does not.
25. [Long dispela ol grup, inap yu makim we antap (1) igo tamblo (7) long wok bilong ol long serim toksave bilong weather na luksave bilong weather?] *[From those groups, can you rank them from highest (1) to lowest (7) in terms of their level of responsibility for sharing information about weather and forecasts of weather?*	**Rank the sources from highest (1) to lowest (7). If the participant gives less than 7 responses, only rank those which they have provided.**	Like Question 18, the Tok Pisin translation is not structured in an appropriate way.
28. [Long taim bilong nogut weather, ol dispela kain hap bilong kisim toksave long weather na luksave bilong weather yu nidim i senis we i wankain long nomol weather?] [*During an extreme weather event, does the type and source for information on weather and forecasts of weather you need change compared to normal*?]	**Selection option (Circle)**	Could be rephrased in both English and in Tok Pisin as both enumerators and participants found it confusing.
29. [Sapos kain hap bilong kisim toksave bin senis long taim bilong nogut weather, long wanem wei em i senis?] [If *the type and source for information changes during an extreme weather event compared, in what way does it change?]*	**Free response (write down the respondent answer)**	Enumerators and participants found it confusing as it was dependent on Question 28.

12.6 Appendix F – summary of community issues

Issues discussed with NARI staff at Aiyura and with villagers at three sites in Eastern Highlands Province

NARI staff at Aiyura were asked the following:

1. What relevant technologies do NARI staff have for drought resistant crops, water tolerant crops or other relevant technology?

2. Are they doing any research at Aiyura on varieties of sweetpotato (or any other crop) which are more tolerant of drought or of very high soil moisture conditions?

Reuben Sengere and Rebecca Amira went to villages in the three sites, that is, Ifiyufa, Okapa and Ontobura, and conduct some interviews with some villagers in those areas. The eight issues discussed were:

1. Have there been any changes in the agricultural system since it was described in Mapping Agricultural Systems of PNG working paper No 8?

2. Are there changes in soil fertility management such as adoption of organic (e.g. coffee pulp) or inorganic (NPK) fertilizer for kaukau, potato or other food crops?

3. What about changes in the crop base? Adoption of West African yam? More cassava? Less winged bean? Other changes in the crop base over the past 25 years?

4. Who are the key DPI contacts in these areas? Are they doing anything to help villagers?

5. Who else is trying to help villagers, any Community Based Organisations, NGOs, churches? Names and contact details for any of these.

6. Is there any evidence that any villager is adopting any of new technology from NARI or other sources, such as NGOs?

7. What are villagers saying about changes in rainfall patterns, temperatures or crop behaviour?

8. How are villagers adapting to any changes in rainfall and temperature, if at all?