Assessing the social and economic value of germplasm and crop improvement as a climate change adaptation strategy: Samoa and Vanuatu case studies

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Report prepared for the International Union for the Conservation of Nature (IUCN)

IUCN

November 2011

Australian Government

Department of Climate Change and Energy Efficiency

AusAid

Australian AID

ISBN 978-1-922003-95-9

This report was supported by funding from the Australian Government under the Pacific Australia Climate Change Science and Adaptation Planning (PACCSAP) program.

Citation: McGregor, A. with Peter Kaoh, Laisene Tuioti Mariner, Padma Narsey Lal and Mary Taylor (2011). 'Assessing the social and economic value of germplasm and crop improvement as a climate change adaptation strategy: Samoa and Vanuatu case studies'. A background case study prepared for IUCN's report, *Climate Change Adaptation in the Pacific: Making Informed Choices,* prepared for the Australian Department of Climate Change and Energy Efficiency (DCCEE), IUCN, Suva, Fiji.

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
BCR	Benefit Cost Ratio
CCA	Climate Change Adaptation
CePaCT	Centre for Pacific Crops and Trees
CIF	Cost, Insurance and Freight
CIP	International Potato Centre in Peru
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
ENSO	El Niño–Southern Oscillation
FGD	Focused group discussions
FOB	Free on Board
FSA	Farm Support Association
FSM	Federated States of Micronesia
HortResearch	Horticulture and Food Research Institute of New Zealand Ltd
IITA	International Institute of Tropical Agriculture, Nigeria
INEA	International Edible Aroids Network
IPCC	Intergovernmental Panel on Climate Change
IPGRI	International Plant Genetic Resources Institute
IPO	Inter-decadal Pacific Oscillation
MAF	Ministry of Agriculture and Fisheries (Samoa)
NPV	Net Present Value
PARDI	Pacific Agribusiness Research for Development Initiative (ACIAR)
PIC	Pacific Island Country
PPB	Participatory plant breeding
PRAP	Pacific Regional Agricultural Programme
SOI	Southern Oscillation Index
SPC	Secretariat of the Pacific Community
SPCZ	South Pacific Convergence Zone
TANSAO	Taro Network for Southeast Asia and Oceania
TaroGen	Taro Genetic Resources: Conservation and Utilisation

TLB	Taro leaf blight (*Phytophthora colocasiae)*
TIP	Taro Improvement Project
UQ	University of Queensland
USP	University of the South Pacific
VARTC	Vanuatu Agricultural and Technical Centre

Exchange rates per unit of foreign currency (mid-market rate July 25th 2011)

	AUD
WST	0.437
VUV	0.00776
FJD	0.555

Source: Universal Currency Convertor

Acknowledgements

The study was coordinated by Andrew McGregor. The study team comprised Laisene Tuioti Mariner, Dr. Padma Narsey Lal (IUCN) Peter Kaoh (Vanuatu Farm Support Association) and Dr. Mary Taylor (Manager SPC, CePaCT).The contributions of Tolo Iosefa (USP Alafua taro breeder), Dr. Vincent Lebot (CIRAD/VARTC), Dr. Mike Bourke (ANU PNG agriculture specialist), Neville Koop (Nadraki (Fiji), Ltd.)and Kalara McGregor (Earth Systems, Ltd.) are particularly acknowledged. So too are the contributions of the numerous farmers in Samoa and Vanuatu who freely shared their root crop knowledge with the team. Karras Lui from the Central Bank of Samoa supplied much of the data that allowed for the economic analysis in the Samoa case study. The study was funded by the Australian Government Department of Climate Change and Energy Efficiency (DCCEE).The data presented, conclusions drawn and the recommendations made are the sole responsibility of the authors.

1. The overview report

Farming systems in the Pacific Island Countries (PICs) are varied and complex and have proven to be usually robust and productive in the face of adversity. Smallholder agriculture has provided a generally high level of food security and has been the ‘hidden strength’ of these otherwise structurally weak economies. However, Pacific island agriculture is highly vulnerable to trends and variability in weather and climatic conditions. Coastal areas are also vulnerable to sea level rise due to climate change and usual variations due to El Niño–Southern Oscillation(ENSO) events and storm surges, causing salinisation of the farming areas. The effects of climate change are already being experienced, with decreases in crop yields, changes in flowering and crop suitability over different altitudes, as well as outbreaks of pests and diseases due to changes in temperature and humidity conditions. Such effects are expected to be exacerbated with projected changes in climate variability and extreme weather events, sea level rise and increased storm surges.

In the face of climate change and a high level of climatic variability, a range of agricultural sector-related climate sensitive and climate ready adaption strategies and coping mechanisms have been recognised for implementation, including:

- enhancing the resilience of traditional and sustainable cropping systems;
- promoting appropriate traditional planting material preservation;
- developing improved germplasm for crops that is better suited to climatic extremes and the

  associated pest and disease problems; and
- ensuring that secure and effective planting material production systems (community, national and regional) are in place.

These traditional farming systems need to be supported by efficient distribution systems (which ensure planting material is available immediately when required or are in advance of climate-induced disease outbreaks taking place) coupled with knowing the climatic limits of the actual crops and varieties.

This case study discusses the cost benefit assessment of germplasm conservation and crop improvement as a climate change adaptation strategy by focusing on two different approaches.

The report presents the findings of two detailed studies:

- Utilizing regional and national germplasm collections as a climate change adaptation strategy: a reactive response to taro leaf blight (TLB) in Samoa
- Broadening the genetic base of root crops in Vanuatu: a proactive climate change adaptation strategy

Reactive response: Taro leaf blight resistant crop improvement

Despite the strength of traditional Pacific island crops and cropping systems in dealing with risk and disasters, there is an underlying vulnerability due to the narrow genetic base of these crops. Most of the taro grown across the Pacific originated in Melanesia. A similar situation exists for other aroids. This makes these root crops particularly susceptible to the impact of diseases brought about by the impact of climate change such as taro leaf blight. TLB is a fungal disease which prefers high night time temperatures and relative humidity. The fungal disease significantly reduces the number of functional leaves, and can lead to yield reductions of over 50 per cent. TLB was first detected in Samoa in 1993, when it rapidly spread across the two main islands, Upolu and Savai'i.

Various factors contributed to the rapid spread of the disease in Samoa, including the mono culture planning of a highly susceptible variety in the aftermath of Cyclone Val. The weather conditions at the time were conducive to rapid spread of the disease, quickly reaching epidemic proportions; strong winds and high relative humidity; high night time temperatures and high relative humidity were ideal conditions for the spread of the fungal spores.

Projected changes in climate across the region, including warmer conditions and a rise in minimum night time temperature and relative humidity, increase the likelihood of TLB spreading to locations that are currently free of the disease. Fiji, Tonga, Vanuatu, the Cook Islands and higher elevation areas of PNG, are all susceptible and are all seen to be at high risk.

The Samoan case study demonstrates that a TLB epidemic represents a major disaster with large economic and social consequences.TLB had a devastating impact on the Samoan taro production, with an annual loss in production valued at Samoan Tala (WST) 25 million (or AUD 11 million) between 1994-1999. For five to six years following the arrival of TLB, little taro was consumed in Samoa, a distinct difference from the1989 census records which showed that almost 96 per cent of agricultural households grew and consumed taro. Taro was also by far Samoa's largest exporter earner. Samoa suffered an annual loss in foregone domestic taro consumption valued at WST 11 million and a taro exports valued at WST 9 million.

Management responses

The initial response to TLB consisted of standard agricultural farm management practices, including spraying of infected planting material with fungicides, which proved to be ineffective. Farmers were reluctant to incur the extra costs involved, even with the government subsidy towards the cost of the fungicide. Although there were also quarantine measures put in place to restrict the movement of planting material, which were also supported by an awareness campaign, the TLB could not be contained as the climatic conditions favoured rapid disease development.

After the conventional disease control methods failed, attention focused on the introduction of exotic varieties resistant to TLB (initially from Micronesia and then South East Asia). Although the introduction and use of these TLB resistant taro varieties enabled Samoan farmers once again to cultivate taro, there was general consensus that these varieties were less than ideal in terms of Samoan taste preferences. Thus, attention shifted towards a longer term breeding of taro, where the challenge was not only to find resistant varieties, but also to meet the demanding taste requirements of Samoan communities at home and abroad, and to provide for a shelf life that would allow export by sea.

The challenge was met by using a classical plant breeding approach which incorporated a high level of grower participation. The initial breeding programme involved University of the South Pacific (USP)plant breeders and the Ministry of Agriculture staff, utilising their own funds. Later external funds of about WST 18 million (AUD 8 million) were incrementally obtained between 1994 and 2010 from partners such as AusAID (TAROGEN project and for support for regional germplasm conservation at the Centre for Pacific Crops and Trees (CePaCT)), ACIAR (DNA finger printing and virus testing protocol development projects), and New Zealand Ministry of Foreign Affairs (assessment of TLB resistance methodology). This programme eventually led to the introduction of locally bred TLB resistant taro varieties in Samoa.

This breeding programme was informed by scientific knowledge, including genetics and crop breeding techniques, and farmer experiential knowledge and farmer trials, as well as community preference trials in Samoa. The preferences of the Samoans living aboard were not initially tested. Farmer participation in the field trials ensured trials across many locations and quick uptake.

Ex-post estimation of economic net benefits of TLB resistant crop improvement as a Climate Change Adaptation (CCA) strategy

Even though TLB resistant crop breeding activities were developed incrementally over time, the cumulative result of the largely publically-funded TLB resistant crop improvement programme far outweighs the costs. Production of taro for the domestic market has increased from virtually zero to 9000 tonnes in 2010. Most of this production was for local consumption, which in 2010 was valued at WST 21 million (AUD 9.3 million). The imputed economic value of this consumption was the value of the rice that would have been imported had this taro not been available.

To this had to be added the value of exported taro. In 2010, taro exports were 330 tonnes valued WST 1.1 million (AUD 0.5 million) free on board (FOB). The value of taro production over the period 1994 through to 2010 was 10 times the cost of the breeding and germplasm conservation programme; the latter was estimated as a prorated cost of the regional CePaCT germplasm conservation programme. Sensitivity analysis, using a range of discount rates, provides a Benefit Cost Ratio (BCR) ranging from 10.7 to 12.5.

To this has to be added the substantial (not quantified) health and nutrition benefits from consuming taro and taro leaves, rather than processed imported grain. Taking into account expected growth in the domestic consumption, considering recent trends in the consumption of rice and wheat, the value of taro is projected to be about WST25 million (AUD 11 million) by 2030. With the projected increase in the markets and continued breeding and extension programme at nominal costs, the projected BCR ranges from 15.1 to 16.4,depending on the discount rate chosen.

The success of the Samoan taro breeding programme can be attributed to:

- A major crisis that made it possible to focus the minds of government decision-makers and donor agencies to eventually secure the necessary coordinated and sustained response of the funding and implementing agencies. Eliciting an ex-ante response of equivalent scale is a much more difficult task – although this is what is now required for other countries and for other traditional crops.
- The high calibre of the key people involved in the identification of project and its subsequent implementation. In particular, the USP taro breeder has, from the outset, been critical to the success of the programme.
- The direct involvement of farmers in the taro breeding programme.
- The existence of regional germplasm banks at SPC and USP.

Importantly, the success of the taro breeding programme was made possible because of the access to diversity through the Pacific region's gene bank, in particular, the south-east Asian taro from the TANSAO project which provided the much needed diversity to progress the breeding programme to the stage it is at today. For Samoa to have imported this material directly would have been very difficult, especially taking into account the need for virus testing. Although the net benefits of the TLB crop breeding programme show significant value, the economic and social benefits could have been much greater if Samoa or the regional germplasm banks had contained key taro genetic material from the region, as well as Asia.

The Samoan programme took several years to get started – which meant there were substantial costs in terms of lost benefits. Initially, several years were wasted following the blind alley of promoting cultural practices to combat the disease. It then took a number of years to get a cohesive crop improvement programme based on genetic material and plant breeding established. Such delays and costs to local communities and loss in the export markets could have been avoided had investment in regional ex-situ germplasm banks been made much earlier.

An important lesson learnt for other countries is the need to be able to respond quickly to the arrival of diseases such as TLB. For this, ready and timely access to diversity through a strengthened planting material distribution system, involving national and regional germplasm banks is essential. However, a complete reliance on regional and national germplasm banks is not an ideal risk management strategy, as ex-situ(off-farm) germplasm banks, especially filed collections, have been known to lose key collections due to diseases, financial constraints, political unrest and other types of incidents. A proactive response is required with the germplasm in-country and, ideally, in the hands of the farmers prior to the arrival of the disease. The Vanuatu programme is an example of how this can be done.

Investing in foundational institutional capacity

Due to the severe consequences of the TLB disaster it was possible to eventually focus the attention and support of national government agencies (primarily the Samoan Ministry of Agriculture),regional bodies (SPC and USP), and development partners (AusAID, NZ AID and ACIAR). To avert similar disasters occurring in other PICs, proactive action is required by these countries for other traditional crops, especially in light of the expected challenges to climate change. Without this proactive approach, the ability of and the time it will take for the countries to recover from these challenges is likely to be severely impacted. An example of such a proactive step in the region is the Vanuatu germplasm distribution pilot project which is analyzed in the second case study.

Proactive response: strengthening flexible and sustainable capacity in Vanuatu

The Vanuatu approach, in contrast to that described for Samoa, relies on evaluating local diversity, incorporating some exotic diversity and then distributing large volumes of planting material for farmers to select from, and then to conserve. This approach relies very much on the interest and enthusiasm of the farmer to want new diversity, and importantly, not to abandon any old traditional varieties for this new diversity. Unlike the more targeted approach as illustrated by Samoa, the diversity in the Vanuatu's farmers' fields is significantly enhanced, which could have huge benefits in managing climatic variations, and pests and disease outbreaks. It remains to be determined if this approach to germplasm conservation is unique to Vanuatu farmers.

Vanuatu, in common with other Pacific island countries and beyond, has a poor record in sustaining germplasm collections in research stations. To safeguard against the loss in genetic diversity in ex-situ (off-farm) germplasm collections, effort is now being made to establish 'collections' in farmers' fields. Vanuatu Agricultural and Technical Centre (VARTC) developed a pilot project to test and evaluate on-farm conservation by introducing new genetic material in Vanuatu's traditional cropping systems, and allowing 'natural' distribution of new genetic material through traditional cultural practices of exchanging planting material. The objective was to broaden genetic diversity in village farmers' fields that included varieties that had some key resistant characteristics. Taste and texture were the most important positive criteria for the adoption of new varieties whereas, the negative agronomic characteristics were the most important criteria for rejecting a variety. By enriching farmers', varietal portfolios protection is provided against future epidemics and biological disasters.

The 'no regrets' adaptation strategy embodied in this pilot project established reservoirs of genetic diversity in taro (*Colocasia spp.)*, yams (*Diascoera spp.)*, sweet potato (*Ipomoea batatas*)and cassava (*Manihot esculenta*) in 10villages across Vanuatu. These villages were classified either as yamor taro-based. "Yam villages" are generally located in the drier areas of the leeward sides. The ‘taro villages’ are located at higher attitude or moist windward side of islands. The planting material was produced on VARTC research stations. The bulking up and distribution has been in collaboration with Farm Support Association, a local NGO. New genetic varieties spread naturally through the cultural exchange mechanisms. Two years after the material was distributed to the 10 villages, monitoring of farmers’ fields indicated a86 per cent net gain in the diversity for yam villages and a 61 per cent gain for taro villages, enriching farmers’ varietal portfolios.

There are significant upfront costs in screening the germplasm material for distribution and establishing new varieties. The cost of that programme was Vanuatu Vatu (VUV) 9 million (AUD70,000), 60 per cent of which was the vegetative field maintenance, with the remainder for inter-island shipping of planting material.

Social and economic assessment

Social and economic assessment of the ‘no regrets’ strategy of establishing ‘reservoirs’ of genetic diversity in farmers’ fields is difficult, as much of the benefits would occur in times of future pest and disease outbreaks, and climate-related disasters. The benefits will also depend on the maintenance of the genetic diversity in farmers’ fields. Assuming new varieties are maintained, the benefits can be measured in terms of imported grain if there is a catastrophic loss of a subsistence crop. It is estimated on this basis, a mere five per cent increase in Vanuatu’s grain imports would have a cost of VUV 67 million (AUD 520,000) per annum. A 25 per cent increase would have a cost of VUV 336 million (AUD 2.6 million) per annum. The probability of Vanuatu having a root crop biological disaster over the next decade that resulted in at least a five per cent increase in grain imports is seen as quite high.

If the full benefits of in-situ germplasm conservation as a climate change adaptation strategy are to be realised in a reasonable timeframe, then consolidation and expansion of the regional and national germplasm conservation and crop improvement effort is now required beyond a pilot project as this case study emphasizes. An outline for such a project, suitable for donor funding is provided in Chapter 4 of this report.

No regrets strategy building on natural risk minimisation strategy

This pilot project demonstrates the potential for building on the traditional practice in the Pacific of maintaining diversity in crop varieties in family gardens, and accessing them in time of need, following changes in climatic and other conditions. By building on the Melanesian cultural practice of openly sharing crop varieties and adopting a proactive ‘no regrets’ approach to maintaining genetic material in regional and national germplasm collections, as well as reservoirs in farmers’ fields, it is then possible to ensure the countries have sufficient genetic diversity to help meet their food and nutrition security, as well as their income needs in the face of climate change. Such a foundational investment can help meet current disaster risks, as well as longer term challenges due to climate change and climate variability.

Germplasm conservation and crop improvement programmes in Samoa and Vanuatu: lessons for strengthening CCA for food security

Key Findings

- The need for farmers to have access to genetic diversity and systems by which diversity can be used and evaluated. This provides farmers with a range of options to deal with the variables of climate change.

- The need to adopt both reactive and proactive measures towards dealing with climate change risks with respect to food security.

- The need for a combined national and regional germplasm conservation and crop improvement programmes, and the need for a flexible and sustainable capacity for future crop improvements.

- The relevance of longer term investment in introducing and conserving diversity in crop genetic material in regional and national collections, supplemented by genetic reservoirs in farmers' fields as proactive 'no regrets' strategies for addressing current and projected changes in risks associated with climate change.

- The importance of investing in foundational institutions to backstop future needs under alternative climate futures. Providing diversity is **not** a once off solution. The nature of climate change demands the ongoing existence of a regional germplasm centre, operating as a hub. This will require substantial long-term funding.

- The CePaCT maintains collections of key traditional crops for the Pacific, including taro, other edible aroids, yam, sweet potato, cassava, and bananas, and it can easily import, multiply and then distribute genetic material as and when required. In the process, CePaCT's presence enables countries to conserve, share, and evaluate their own resources and more effectively take advantage of developments outside the region. This puts the countries in a better stead to produce other climate resistant or climate ready improved crops over time as and when changes in climate are experienced. As such, linked regional and national systems, where present, could enable countries and the region to better manage climate change.

- The immediate climatic risks must be urgently addressed, while also preparing for projected changes.

- The demand for disease-resistant root crop germplasm is not perceived by the growers as an adaption to climate change. It is seen as meeting their current vulnerability to loss in crops due to disease. However, the approach adopted is easily replicable to produce crops suitable under alternative climate change scenarios.

- The introduction of new genetic material and the maintenance of this genetic diversity in farmers' fields provide insurance against future outbreaks of diseases which are likely to occur given the projected changes in climate change in the region.

- The success of the TLB-resistant taro breeding programme in Samoa and the proactive 'no regrets' approach to crop germplasm conservation adopted in Vanuatu emphasise the importance of adopting a holistic and systematic approach to climate risk management on several levels.

- The case studies demonstrate that adaptation activity in the agriculture sector that targets specific 'root causes' of observed diseases related to climate change effects can have very high net economic returns.

- Meeting the immediate needs of village farmers, as well as their active involvement in the research phase, ensures quick uptake of new genetic material.

- The need to adopt integrated scientific, social science and traditional knowledge to address current and projected biological and climatic risks and to identify appropriate response solutions.

- The challenges of climate risk could at times be beyond the capacity of any one organisation, and strong partnerships across agencies and countries may be required; and the importance of strong public/private sector/community partnerships to help keep down costs of trials and swift adoption by farmers once new varieties show promise.

Identified projects requiring substantial support

The case studies identified several priority projects, the implementation of which could expect high economic rates of return. These are:

- Long-term and expanded investment in CePaCT.

- Replicating of Samoa's taro breeding programme in Fiji, where the arrival of TLB is likely to be inevitable.

- The scaling up of the Vanuatu pilot 'in-situ' conservation project to a national programme.

- Replicating the Vanuatu pilot conservation project in other Melanesian countries, with a particular emphasis on sweet potato as the main food crop.

Donor support will be sought for the detailed design and implementation of all four projects.

2. Climate change and Pacific island agriculture and food security

Traditional Pacific island crops and cropping systems

Coping with risk and disasters

Most traditional Pacific island subsistence crops are of high nutritional value. Many mature in less than a year and are grown on custom land. Virtually all inputs are supplied within the system so there is no requirement for formal title, working capital and credit, all of which are major constraints to commercial agricultural development. Furthermore, the technologies of Pacific Island cropping systems are well established and these countries have developed efficient mechanisms for dealing with risk.

These small holder farming systems are complex and have proven to be robust and productive in the face of adversity. In varying degrees they have proven to be the hidden strength of these otherwise structurally weak economies. Events of recent times provide ample evidence of the economic importance of these traditional small holder-farming systems. These include:

- The rapid recovery of the Samoan economy, following successive natural (cyclones) and biological disasters (taro leaf blight).
- The remarkable turnaround of the Fijian economy, following the devastating “100 year” drought of 1997/98.
- The tempering of the humanitarian disaster associated with the ethnic conflict in the Solomon Islands and the civil war in Bougainville.
- The production response of PNG root crop growers to the sharp increase in imported grain prices, following depreciation of the kina in 1994.

The underlying vulnerability of traditional Pacific island crops

Despite the strength of traditional Pacific island crops and cropping systems in dealing with risk and disasters, there is an underlying vulnerability due to the narrow genetic base of these crops (Lebot, 1992). For example, according to the DNA analysis, most, if not all the taro grown across the Pacific originated in Melanesia, and particularly Papua New Guinea and Solomon Islands (ACIAR, 2011). A similar situation exists for yams, cassava, sweet potato and other aroids. This makes these root crops particularly susceptible to the impact of diseases brought about by the impact of climate change such as taro leaf blight.

The genetic vulnerability of Pacific islands root crops is explained by Dr. Mary Taylor, the Manager for the Centre for Pacific Crops and Trees (CePaCT).

> Taro would have been carried by canoe eastwards from these islands and gradually introduced across the Pacific region. But because taro is vegetatively propagated—reproduced from cuttings rather than seeds—there was little opportunity for new varieties to develop; this is why we have ended up with limited diversity. The solution to the leaf blight problem was to look outside the region for resistance genes—to South-East Asia, which is believed to be a second centre of diversity for taro (ACIAR 2011).

Trends and extreme climate cycles in the Pacific island region

Climate trends

The observed climate trends cited by the Intergovernmental Panel on Climate Change's (IPCC)'s Working Group II chapter on small islands include:

- Annual and seasonal ocean surface and island air temperature have increased by 0.6 –1.0°C since 1910 throughout a large part of the region, southwest of the South Pacific Convergence Zone
- More hot days and warm nights, and significantly fewer cool days and cold nights, particularly in years after the onset of El Niño events
- Analysis of satellite and tide gauge data show a maximum rate of sea level rise in the central and eastern Pacific, spreading north and south around the sub-tropical gyres of the Pacific Ocean near 90°E, mostly between 2 and 2.5 mm/year, peaking at over 3mm/year for the period 1950–2000

Expected climate trends for the Pacific islands reported by the New Zealand National Institute of Water and Atmospheric Research include lower overall annual rainfall, more high intensity rainfall events, increased average temperatures, increased cyclone frequency and intensity, and rising sea-levels(NIWA, 2010). Colins, et.al (2010) suggests that:

> There is a consensus that due to the influence of global warming, the mean climate of the Pacific region will probably undergo significant changes. The tropical easterly trade winds are expected to weaken; surface ocean temperatures are expected to warm fastest near the equator and more slowly farther away; the equatorial thermocline that marks the transition between the wind-mixed upper ocean and deeper layers is expected to shoal; and the temperature gradients across the thermocline are expected to become steeper (p, 1).

What is far less clear are future expectations with respect to climatic extremes due to the naturally occurring El Niño–Southern Oscillation (ENSO) cycles and the extent that these will be influenced, if at all by climate change.

Temperature

Data is presented here for Fiji, PNG, Samoa and Vanuatu which is taken to be representative of the region.

Fiji

Analysis of daily data records for Fiji over the period 1961-2003 show a 0.25 ^{o}C increase per decade for Suva and a 0.07^{o}C increase per decade for Nadi (Mataki, et.al 2006). This compares with a global increase per decade of 0.17^{0}C (IPCC, 2001). At Nadi, the trend in annual mean maximum temperature over this period is not significant, but the increasing trend displayed in annual mean minimum temperature is significant and is most prominent since the early 1990s. At Suva, both maximum and minimum temperatures exhibit significant increasing trends. The observed increases in night time minimum temperature at both Nadi and Suva is consistent with global mean night time minimum temperature, which has increased at twice the rate of daytime maximum temperatures during the period of1950 to 2000 (IPCC, 2001).The finding on increasing minimum temperature is particularly important from an agricultural perspective.

Papua New Guinea

Bourke and Harwood (2009) report that PNG temperatures have increased during the 20thcentury, with most of the increase occurring from the mid-1970s (p.75). For PNG, as with Fiji, the rate of temperature increase was greater for the minimum than for the maximum temperature. An analysis of temperature change for nine coastal locations found that the minimum, mean and maximum had increased by an average of 0.2^{o}C per decade over the period of 1951 to 1999. Temperatures tended to be lowest in El Niño and highest in La Niña years.

Long term temperature data runs are not available for most highland locations in PNG. However, the data that is available does suggest similar trends as at lowland locations. For example, Bourke and Harwood report that at Aiyura in the Eastern Highlands, the maximum temperature increased by 0.3^{o}C per decade over the period 1977-2001.

Samoa

Samoa is the focus of the second case study. The length of maximum temperature records for Samoa is quite short. Data from 1993-2006 shows considerable inter-annual variability in the extreme air temperature, and there is an indication of a rising trend in the maximum air temperature (Hay, 2006). A maximum air temperature of at least 32^{0}C is still a relatively rare event at Apia, with a return period of approximately 11 years (Hay, 2006, p.20).

Vanuatu

There is limited historic climatic data for Vanuatu with records back to 1949 for the capital Port Vila on Efate and 1973 for Luganville on the more northern island of Espiritu

Santo. Average temperatures range between 21°C and 27°C and average humidity ranges between 75 per cent and 80 per cent (FAO, 2008, p. 31). Trends suggest a gradual increase in temperature that is more marked in the south, with a higher level of statistical significance, than in the north (figures 1 and 2) (FAO, 2008, p. 31).

Rainfall

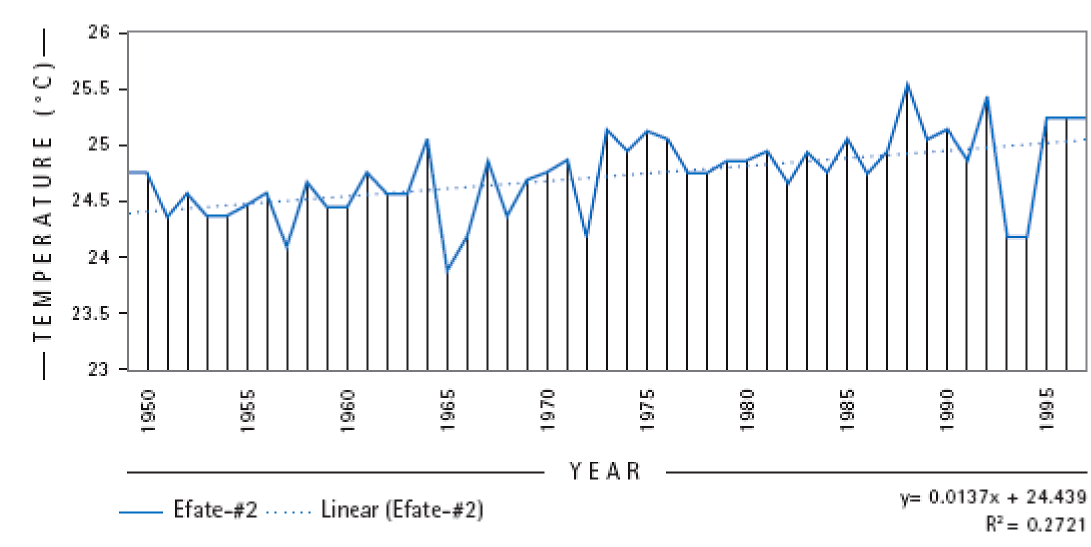
Fiji

Mataki, et.al, 2006 examined long-term precipitation changes in Nadi and Suva for the 43-year period ending in 2003. The data showed no discernable increasing or decreasing trend in the annual total rainfall at either of the two locations over the 1961 - 2003 period.

Papua New Guinea

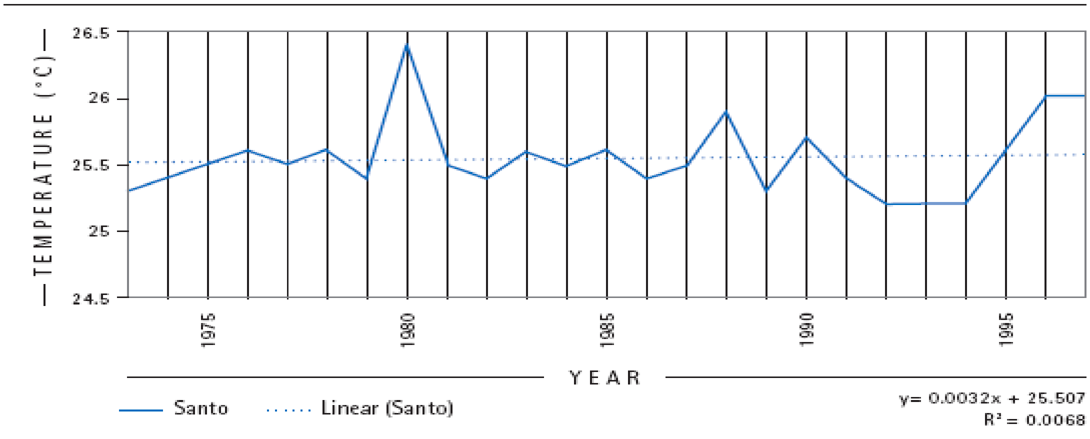
Bourke and Harwood note that the majority of rural rainfall recording stations ceased operations around 1980, resulting in a loss of information about rainfall. However, there are very widespread reports by villagers that seasonal rainfall patterns in both the lowlands and highlands are less predictable than in past decades. There are indications that annual rainfall is increasing in some locations and decreasing in others. However, there is no overall trend and it is not clear whether there is a significant increase or decrease in annual rainfall (Bourke and Harwood, p. 77; Mike Bourke, pers. comm., 2011).

Figure 1 Annual mean temperature Nambatu (Efate) – 1950 -1997*



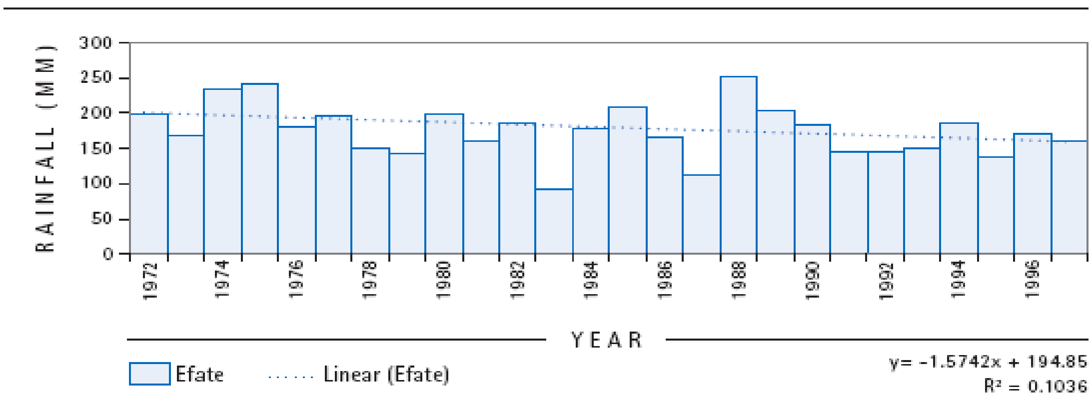
* Source FAO, 2008, p 46

Figure 2 Annual mean temperature Pekoa (Efate) – 1950 -1997*



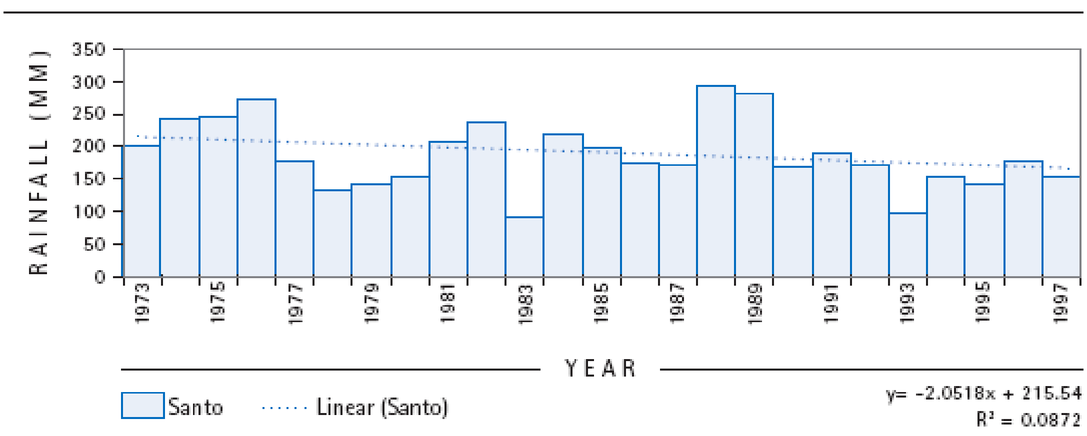
* Source FAO, 2008, p 46

Figure 3 Average annual rainfall, Nambatu (Efate) – 1972-1997*



* Source FAO, 2008, p 46

Figure 4 Average annual rainfall, Pekoa (Santo) – 1972-1997*



* Source FAO, 2008, p 46

Samoa

Daily, monthly and annual rainfall for Apia (1972-2005) shows high variability, including extremes (Hay, 2006, p. 9). However, no significant long-term trends are evident in any of the three time series.

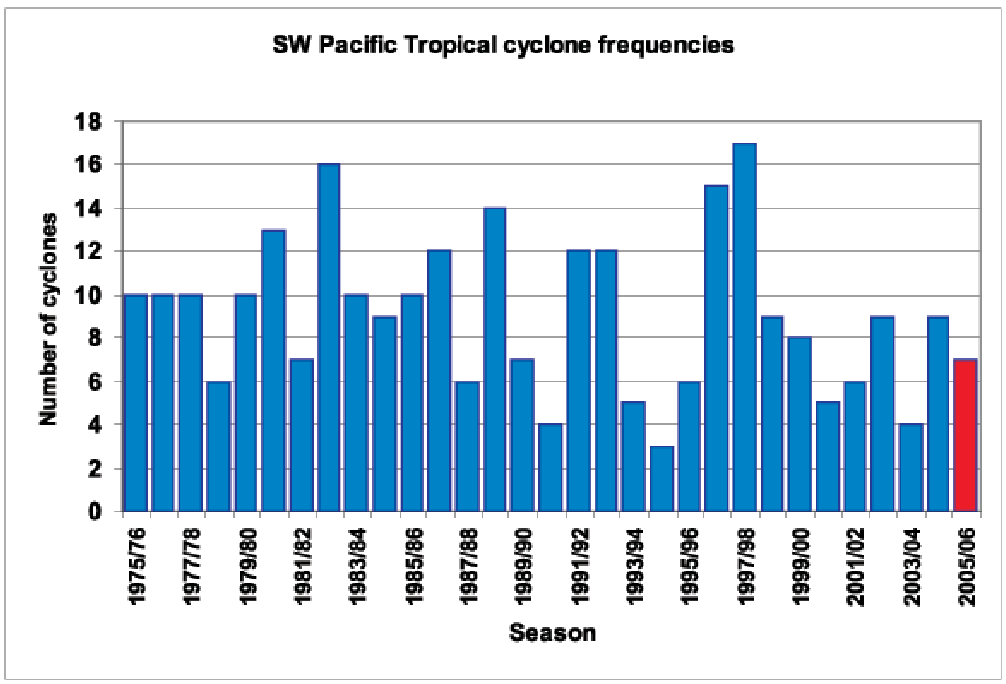
Vanuatu

In Vanuatu, average rainfall declines from over 4000mm in the north to less than 1500mm in the south (Mourgues, 2005). There has been a gradual decline in rainfall overall with a higher level of statistical significance on Efate than for Santo (figures 3 and 4).

Cyclones

Comprehensive data on the frequency of tropical cyclones has only been available since the mid-1960s with the advent of satellite imagery. This short time series suggests no discernable trend in the frequency in the south west Pacific (figure 5).

Figure 5 The frequency of tropical cyclones in the South West Pacific (1975 – 2006)*



* Source: Burgess, 2006

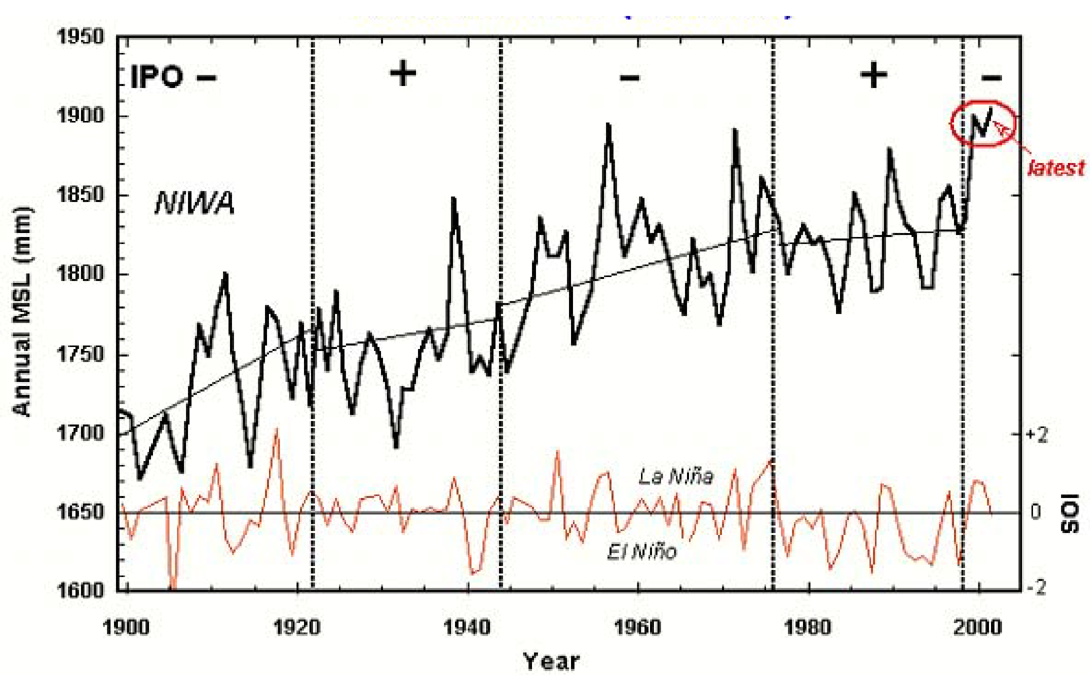
While the data does not indicate an upward trend in the frequency on tropical cyclones for the Pacific islands, there are global indications of increasing intensity of some cyclonic events. Emanuel (2005) in a paper published on Nature pointed to the increasing destructiveness of tropical cyclones over the past 30years. Emanuel's paper goes on to conclude:

> This trend is due to both longer storm lifetimes and greater storm intensities. I find that the record of net hurricane power dissipation is highly correlated with tropical sea surface temperature, reflecting well-documented climate signals, including multi-decadal oscillations in the North Atlantic and North Pacific, and global warming. My results suggest that future warming may lead to an upward trend in tropical cyclone destructive potential, and—taking into account an increasing coastal population—a substantial increase in hurricane-related losses in the twenty-first century.

Sea level rise

Long-term sea level varies at timescales of years, decades and centuries. However, since 1998, the Pacific-wide climate regime has shifted to a negative phase of the Inter-decadal Pacific Oscillation (IPO), accompanied by a strong La Niña period and sea level has risen again.

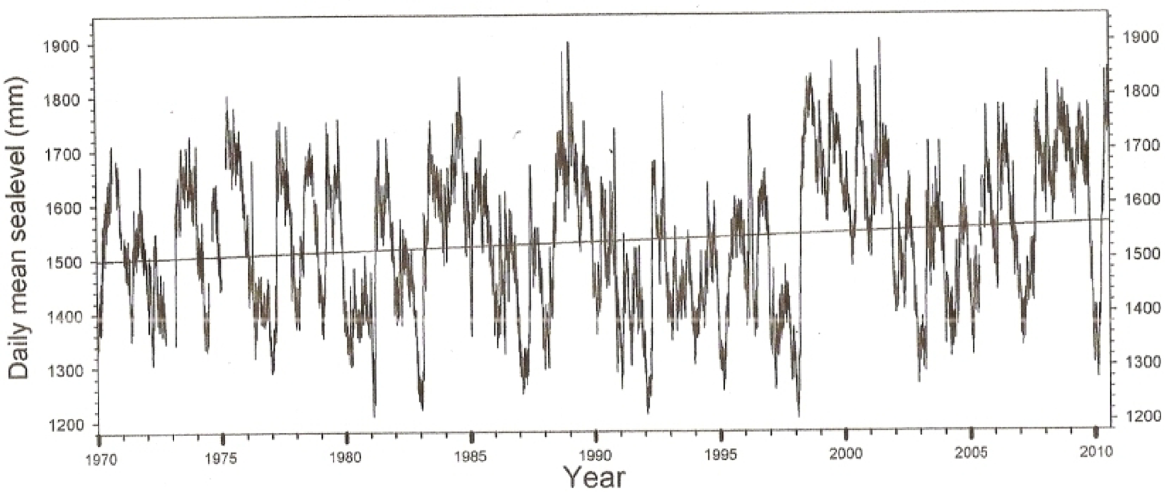
Figure 6 Average annual tide level for the Port of Auckland (1899-2001)*



*source: NIWA New Zealand http://www.niwa.co.nz/our-science/natural-hazards/research-projects/all/physical-hazards-affecting-coastal-margins-and-the-continental-shelf/news/hazard

A similar pattern is observed for Koror harbour, Palau in the Northern Pacific, where tidal data has been collected since 1970 (Figure 7). These data show an average rise of 1.5 mm/yr.

Figure 7 Daily mean sea level for Koror harbour (Palau)*



*source: Hawai'i Sea Level Centre data – supplied by Patrick L. Colin Coral Reef Research Foundation, Koror Palau

For Samoa, sea level data collected over the period 1993-2005, show a much larger increase compared to the other locations mentioned above. The observed long-term trend in sea level for Apia is 5.2 mm/yr (Hay 2006, p. 5). This is well above the observed increase cited above for Auckland, Suva, Koror and Port Vila harbours and is referred to by the IPCC's Working Group II chapter on small islands.

FAO (2008) reported for Port Vila, Vanuatu an estimated sea level trend of 3.1 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows (p, 44). Accounting for "the precise levelling results and inverted barometric pressure effect", the revised trend estimate is + 2.2 mm/year.

Climate cycles and extremes

Around the trends of temperature, rainfall, sea level and cyclones frequency there are pronounced climatic cycles and extremes. For the Pacific islands the most dominant of these influences is the El Niño–Southern Oscillation (ENSO). ENSO is a naturally occurring global phenomenon that has existed for millennia (Grove 1998). In the ENSO, the temperature of the sea, the air pressure over the sea and the circulation of the air across the oceans move together, from one extreme to another[1]. El Niño events, which occur every three to eight years or so, are defined by warmer than normal sea surface temperatures in the eastern tropical Pacific, and are associated with anomalous atmospheric circulation patterns known as the Southern Oscillation.

For most of the south west Pacific, including PNG, an ENSO cycle is accompanied by periods of low rainfall and higher cyclone activity (during the El Niño phase) and periods of high rainfall and lower cyclone activity (during the La Niña phase). However, for the atoll countries in the equatorial Pacific Ocean (Kiribati, Tuvalu and Nauru) the La Niña phase can be accompanied by below average rainfall. The extreme drought conditions experienced in Kiribati in 2010/11 corresponded with a prolonged La Niña[2]. The La Niña that prevailed between late 2010 and early 2011 was one of the strongest observed, in a record dating from the late 1800s (per. com. Neville Koop). It brought above average rainfall in Fiji and Samoa and drought to Kiribati and Tuvalu.

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[1] Pacific island meteorological expert Neville Koop, tells that the Southern Oscillation refers to the shifting pattern of air pressure between the Asian and east Pacific regions, known as the Walker Circulation. The strength and direction of this pattern is one indicator of La Niña and El Niño; it is measured by the Southern Oscillation Index (SOI). The SOI measures the difference in air pressure between Tahiti and Darwin (representing the central-east and west of the Pacific Ocean Basin, respectively). The SOI is best represented by monthly or seasonal (or longer) averages since daily or weekly SOI values can fluctuate markedly due to short-lived, day-to-day weather patterns. Sustained positive SOI values are associated with La Niña events while sustained negative SOI values indicate an El Niño. Historically, La Niña events are associated with wetter than normal conditions across the south-west pacific, including Papua Guinea and Fiji. The warm water gathered closer to our archipelago is a source of atmospheric convection and is associated with cloudiness and rainfall. Combined with stronger than normal trade winds, this provides more moisture to the atmosphere and directs the moisture towards Fiji. In the past, La Niña years have been correlated with an increased chance of wetter spring and summer rainfall in Fiji. While higher numbers of tropical cyclones occur in the south-west Pacific during the cyclone season (November to April), most are concentrated to the west near Australia. Overall, tropical cyclones are slightly less frequent around Fiji during La Niña years. During El Niño events, as well as a sustained period of negative SOI, sea surface temperatures in the central and eastern tropical Pacific Ocean are warmer than normal; the focus of convection migrates from the Australian/Indonesian region eastward towards the central tropical Pacific Ocean; and trade winds (easterlies) are weaker than normal. This results in less atmospheric moisture available for rain in the south-west pacific. In the past, El Niño years have been correlated with moderate to extreme drought conditions in PNG and Fiji. Due to the complexity of land-ocean interactions across the Pacific, no two La Niña events, and no two El Niño events, are exactly the same. Similarly, the SOI cannot accurately predict rainfall for Australia on an event by event basis. Rather, indicators of the El Niño-Southern Oscillation serve as a guide to the chance (probability or likelihood) of receiving more or less rainfall in a given season.

[2] This is explained by Neville Koop as follows: "La Nina will lead to drought in Kiribati because the South Pacific Convergence Zone (SPCZ) moves south and the warm water pushes west towards PNG and the Solomon Islands with cooler than normal water along the equator from South America to the date line. The upward branch of the Walker Circulation shifts westwards and, as a result, less rain falls along the equatorial Pacific ocean. Nauru is similarly affected."

ENSO cycles and climate change

Salinger, *et.al* (1996) concluded that ENSO is a very significant phenomenon that accounts for much of the inter-annual variability of climate and sea level in Oceania (p.124). They projected that ENSO is likely to continue to be a significant source in climate variability for the region and is not directly related to a longer term climate warming trend. In the same vein, Brian Dawson, SPC's Senior Climate Change Advisor notes that

> Undoubtedly, climatic variability over the short to medium term will be dominated by what stage of ENSO we are in, hence the biggest effect on crops. ENSO is also the biggest effect on the frequency and intensity of drought and storm activity over the short term. The big question is whether El Nino or La Nina stages of ENSO will be more frequent and intense. The scientific evidence is mixed and, at present, it is not possible to project how ENSO will behave with climate change. In the past (over the multi-million year record), there has been a correlation between global mean temperature and intensity of El Nino – La Nina. In general in a warmer world, there is evidence that El Nino becomes more pronounced as the average state (not good for the western Pacific). However, that does not mean that will occur again. There is also some evidence that that the El Nino intensity has been higher in the last 20 years than the last 100-year average. Also, La Nina events have been rare but the latest has been unusually strong (pers. comm. April 2011).

Collins, *et.al,* 2010, in their review article, *The impact of global warming on the tropical Pacific Ocean and El Niño* conclude: "despite considerable progress in our understanding of the impact of climate change on many of the processes that contribute to El Niño variability, it is not yet possible to say whether ENSO activity will be enhanced or damped, or if the frequency of events will change" (2010, p. 1). Accordingly, for the purpose of this study, the advice of the Pacific Climate Change Science Programme is to assume "no change in climate variability associated with the El Niño Southern Oscillation (ENSO) due to a lack of consensus in ENSO projections" (April 2011).

The impact of ENSO on Pacific island rainfall

Brookfield (1989) found that Indonesia had records of major and catastrophic droughts, dating back to the 1600s which were likely to have been ENSO-induced events. Grove (1998) refers to severe ENSO drought events being recorded in historical records in A.D. 1396 and A.D. 1685–1688.

For the Pacific islands, there is an evident correlation between severe drought and El Niño events. Benson (1997) reports that the severe Fiji droughts of1987and 1992were associated with ENSO episodes. An even more severe El Niño-induced drought was experienced in Fiji and across western Melanesia in 1997-98. The Fiji Strategic Plan at the time suggested that this'100year' event was probably the worst natural disaster the country has ever experienced, far exceeding the impact of any recorded cyclone (Government of Fiji, Ministry of Economic Planning,1999).

For Papua New Guinea, Allen (1997), observing data, dating from 1888 reports that severe drought with accompanying frost and forest fires occurred in1902, 1914, 1941, 1972, 1987, and 1997. He concluded that, "the statistical association between measures of ENSO severity and the physical impact of these in terms of drought and frost is reasonable, but by no means perfect."The 1997drought was the worst, most widespread recorded natural disaster that Papua New Guinea has experienced. Below average rainfall began in April 1997 and was well below average for the rest of the year. The drought was compounded in the highlands by unusually cold frosts. The Australian Government/NGO assessment team reported in December 1997 (Braumann, 1998):

- **Severe food shortages**: In the highland provinces above 2,200 meters, the staple food, sweet potato *(kaukau)*, had been completely eliminated by frosts that began in early June. These areas had no food remaining in the ground. Fires had substantially reduced the remaining bush food. There were also heavy losses to coffee, the main cash crop. Many people had, in traditional fashion, migrated to lower frost-free areas. But these places could not accommodate the migrants to the extent they had in the past because they, too, were affected by drought and the population in these receiving areas had doubled in the past 30 years.

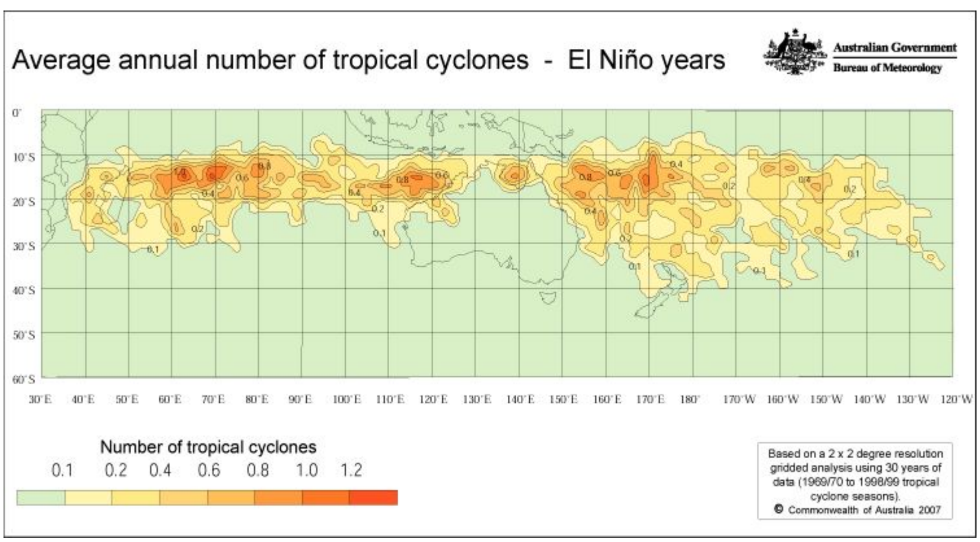
- **Critical water shortages**: At the end of December 1997, an estimated 260,000people lacked access to fresh water. Key institutions such as hospitals, health centres, aid posts and schools were forced to close.

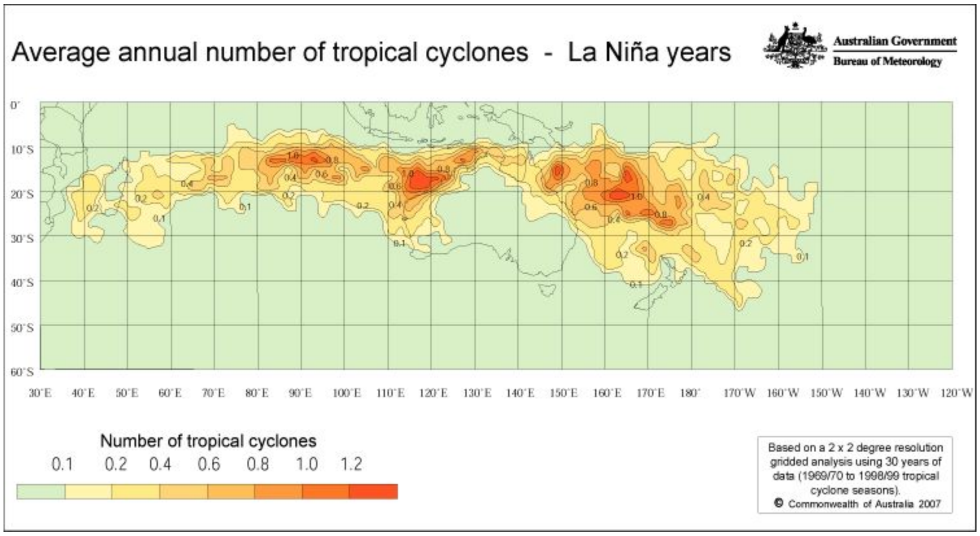
- **Health problems**: There was a marked increase in diarrhea, skin and eye infections, malaria and other diseases.

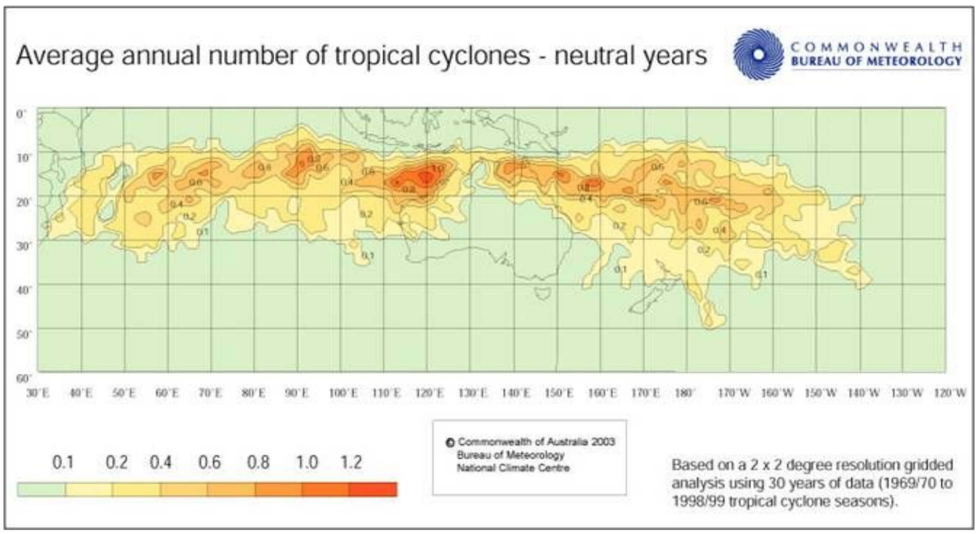
ENSO and cyclones

Cyclone activity for the Pacific islands region tends to be much more pronounced during El Niño periods and less pronounced during La Niña period. Overall, cyclones are more frequent during a La Niña period, but are concentrated around Australia. This is reflected in the graphs produced by the Australian Bureau of Meteorology (Figure 8).

Figure 8 Cyclone frequency during the ENSO cycle







Implications of climate trends and extremes for Pacific islands agriculture

Trends in climate (climate change)

In the case of PNG, Bourke and Harwood (2009) note that climate change is already influencing agriculture but, in most cases, it is unclear what the outcomes will be (p. 78). The same conclusion can be drawn for other PICs. The reason for this is that not enough is known about the probable changes in patterns of rainfall and temperature and rainfall extremes, together with the frequency and intensity of cyclonic events. Agriculture's response to climate change will be complex and will depend on how people, plants, together with insects and diseases, respond. Following Bourke and Harwood, the implications of climate trends on agriculture can be broadly categorized into temperature, rainfall and sea level rise.

Temperature and agriculture in the Pacific islands

Increases in maximum and minimum temperature are already having a small influence on agricultural production in PNG and will have a greater influence in the future. Bourke and Harwood note that:

> Some crops are bearing at higher altitude in the highlands. Given the direct relationship between altitude and temperature in PNG, it is likely that many crops will be grown at marginally high altitudes in the future and the areas where they are grown will expand. However, the lower altitude of some crops, such as Irish potato, Arabica coffee, will increase because of increasing temperature (p, 78).

Sweet potato is by far the most important food staple for western Melanesia. In PNG, it provides almost two thirds by weight of staple food crops (Bourke and Harwood,2009, p. 78). In the Solomon Islands, sweet potato is the most important locally grown food and accounts for an estimated 65 per cent of locally grown staple foods (Bourke, et al., 2006: Table 8.1). Sweet potato is also assuming greater importance in ni-Vanuatu farming systems (McGregor, 2009). However, the most important food crops in Vanuatu still remain Colocasia taro, banana, soft yam, cassava, Xanthosoma taro (Fiji taro) (Bourke, 1999).

Spence and Humphries (in Labot, 2009) found that sweet potato produces the greatest increase in storage weight when grown over a constant soil temperature of 30^{o}C, combined with a night air temperature of 24^{o}C (p. 132).Significantly, Bourke and Harwood (2009) report that tuber production in PNG is reduced significantly at temperatures above 34^{o}C. The maximum temperature in lowland locations in western Melanesia is currently around 32^{o}C. Thus, as Bourke and Harwood predict, increasing average temperatures could reduce sweet potato production in lowland locations with, perhaps, one or two generations[3]. Such a situation could be significantly exacerbated by severe ENSO-induced drought events. Bourke and Harwood also point to the possibility of the incidence of some diseases increasing with increasing temperature, particularly those influenced by rainfall and humidity (p. 79). They make particular reference to the fungal disease taro leaf blight (*Phytophthora colocasiae),* which is the focus of the Samoan case study in this report. Taro leaf blight (TLB) in PNG is less severe a few hundred meters above sea level and is rarely found above the altitude of 1,300 m (Bourke, 2010). This indicates the fungus is sensitive to just a small rise in temperature.

A number of studies have examined the relationship between the spread of TLB and temperature and relative humidity (CABI, Trujillo and Putter). The impact of night temperature on relative humidity would appear to be the key factor in the rapid spread of this disease[4]. The implications of climate change are that higher altitude areas

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[3] This would seem to be a fairly likely event given that The Stern Review calls stabilizing green house gas atmospheric concentrations at ≈550 part per million (ppm) of CO_2 equivalent. This would make temperatures ≈ 2^0 higher and would stabilize future temperatures at ≈ 3^0 higher. More likely, projections of CO_2 equivalent put temperatures above ≈ 2.5 ^{0} higher a century from now and continuing to rise to well above 3^0 higher (Weitzman, 2007).

[4] Putter (1976) found that temperature and relative humidity together explained 72.57 per cent of the variation in sporulation, with all these associations being highly significant (P<01). Grahame Jackson notes that In the coastal

where temperatures are currently outside the optimum range for sporulation at night will warm and the incidence of the disease will increase. The same will occur in cooler PICs where taro is grown such as Fiji, Tonga, and Vanuatu. As summarised by Jackson, climate change means that countries where the disease does not now occur and might be thought to have seasonal climates which would now slow disease development will become more vulnerable. In these countries, spread would be a factor of rainfall, as it is in countries where epidemics now occur.

Rainfall and agriculture in the Pacific islands

The IPCC predicts higher overall rainfall in the South Pacific. However, data for the last 40 years for Fiji and PNG are yet to show any discernable trend. Bourke and Harwood show that for PNG, rainfall patterns are complex and it is likely that any changes in rainfall patterns will also be complex and so, difficult to predict. A similar situation can be expected to prevail for the rest of Western Melanesia. Most areas in these countries already receive high levels of annual rainfall that create constraints for agricultural production. For these areas, an increase in total rainfall and less seasonal distribution would be detrimental to agriculture. This would include such things as increased incidence of fungal diseases and lower levels of solar radiation which adversely affect plant productivity and growth. For example, Mike Bourke notes that in PNG:

> The TLB epidemic was worst where rainfall was continuously high, including on Bougainville (and all the Solomon Islands chain), and much of New Britain. It hit Manus very hard in mid-1975; and hit the Popondetta area badly (and all that coast) in ca 1980 as well as the area north of Telefomin in the lowlands (again in ca 1980) (per com. May, 2011).

In a few of the drier areas, such as the Guadalcanal Plains in the Solomon Islands and western Viti Levu and western Vanua Levu in Fiji, an increase in overall rainfall and less seasonal distribution would be beneficial overall to agricultural production. Although it would be detrimental to some crops such as those which require a distinct dry season to induce flowering.

Sea level rise and agriculture

An average annual sea level rise of around 1.5mm over the last 40 years has not yet impacted on Pacific islands agriculture, except for the low lying atoll countries. However, a much higher average sea level rise has been reported for Samoa. Even with atoll countries, the ENSO driven extreme fluctuations in tides have been far more damaging than any increase in average tide levels. The combination of rising average seas level and extreme ENSO events have contaminated the fresh water lens that feeds the patches where swamp taro is grown. This has happened in Mortlock Island atoll east of Bougainville (Bourke and Betitis, 2003), Tuvalu (McGregor and McGregor, 1999), Kiribati (Tuioti, 2011) and Palau (McGregor, 2011 and Tuioti, 2011).

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areas of PNG and the Solomon islands, temperatures are high enough at night, every night, for abundant sporulation to occur, with RH greater than 95 per cent (per comm. May 2nd, 2011).

It can be expected that the problem of salt water contamination will be further exacerbated in the future with wide ENSO induced tidal fluctuations around an ever-increasing (albeit gradual) increase in average sea level. This has serious implications for subsistence food production in locations where it is already seriously stressed.

Future ENSO cycles and climate change

There is insufficient information for predicting that ENSO cycles will be more or less extreme in the future as the result of climate change. Thus, for the purpose of this report, it is assumed that ENSO events of varying degrees of intensity will occur every three to eight years. Over the last 30 to 40 years, there has been considerable annual variation in rainfall, tidal levels and the incidence of cyclones – during this period, a number of extreme climatic events have occurred that have had substantial impacts on Pacific islands agriculture and food security and the economies as a whole. Pacific island farmers can expect to face more of the same for the next 30 to 40 years.

Climate Change adaption strategies for Pacific island Agriculture

Into the future, Pacific island farmers will face extremes of climate – be this is in the form of excessive and prolonged rainfall and flooding, extended droughts, severe cyclones and exceptional tides. These extreme climatic events threaten the food security of farm households and their economic wellbeing. They will also have major negative impacts on already fragile economies. However, it is immaterial to farmers if these events are caused by climate change, or naturally occurring ENSO cycles, or a combination of both. What is important is that Pacific islands farmers be given the best opportunity to be able to adapt to these extremes to an extent that is feasible. The premise of this study is that by adapting to these extremes in the medium term, future generations of farmers will be better placed to adapt to the challenges of climate change in the longer term.

In the face of a high level of climatic variability, there are a range of adaption strategies and coping mechanisms that can be done through national government and donors. These include:

1. Enhancing the resilience of traditional and sustainable cropping systems.
2. Promoting appropriate traditional planting material preservation.
3. Developing improved germplasm for traditional crops that is better suited to climatic extremes and the associated pest and disease problems.
4. Ensuring that secure and effective planting material production systems (community, national and regional) are in place. These systems need to be supported by efficient distribution systems (which ensure planting material is available immediately when required), coupled with knowing the climatic limits of the actual crops and varieties.
5. Developing of off-farm income earning opportunities as a safety net against extreme climatic events and other disasters.
6. Relocation of households within country or to neighbouring developed countries.

This study deals with the first four of these strategies and coping mechanisms with a particular focus on three and four. The first two strategy options are discussed briefly below. Strategies five and six are outside the scope of this study.

As a result of the findings of these case studies, it is anticipated that national and donor agency decision makers will be better informed of the risks posed to Pacific island food security by climate change and climatic variability. There should also be an appreciation of the economic value of germplasm development, distribution and maintenance as a response to climate change. Armed with this knowledge, these policy makers will be in a better place to make informed choices and public investment decisions in a longer term national development context.

3. Utilizing regional and national germplasm collections as a climate change adaptation strategy: The case study of taro leaf blight in Samoa

The Samoa case study profiles the more structured approach, using diversity imported into a regional gene bank, breeding specifically for the needs of the country at the time, and then returning the “best” outputs of that breeding programme to the regional gene bank for virus testing and safe distribution to other countries in the region and globally. This approach maximises the benefits from one breeding programme through enabling wider outreach of the resulting breeding lines. It also focuses all efforts on a problem and solves that problem effectively, but it is time-consuming. It enhances the diversity that reaches the farmers’ fields, but this enhancement is targeted.

Case study background

Taro leaf blight (*Phytophthora colocasiae*): an example of a biological disaster likely to increase with climate change

The introduction of a plant pest or disease can have a far greater long-term impact than physical disasters. A cyclone may last for several hours to a few days but has a discrete end, after which relief and rehabilitation begin. A drought will last much longer, but is eventually broken. The impact of the incursion of a major pest or disease, by comparison is open ended and may never end. Over the years, incursions of pests and diseases have had a major impact on Pacific island agriculture. Examples include:

- rhinoceros beetle (coconuts in most PICs);
- fruit-sucking moth (fruit in most PICs);

- giant African snail (leafy vegetables in several PICs);
- cocoa pod borer (Bougainville);
- coffee rust (PNG);
- fruit fly (melon fly - cucurbits in the Solomon islands), Oriental fruit fly (in PNG and Palau)
- papuana beetle (taro Vanuatu, parts of Fiji)

However, nothing has matched the impact caused by taro leaf blight-TLB *(Phytophthora colocasiae)* on taro production in PNG and Solomon Islands and more recently in Samoa. The disease has also been recorded in American Samoa, Federated States of Micronesia, Guam, Hawai'i, Northern Mariana Islands and Palau (ACIAR, 2008). The economic and food security impact of TLB in Samoa has been particularly great because taro was the main subsistence crop and largest export earner.

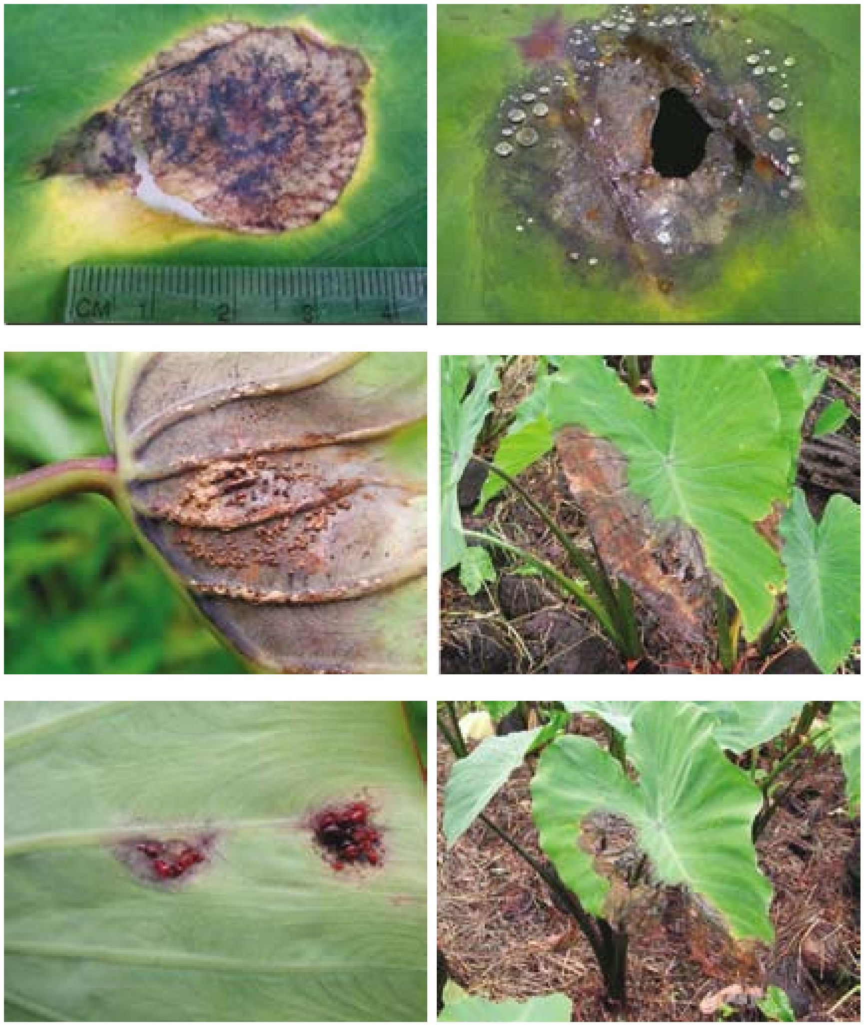
What is TLB

Phytophthora colocasiae is a water mold whose origins are thought to be in South East Asia (Brunt et.al, 2001). It was first identified in Java more than a century ago and is now found throughout the taro producing world.

TLB is mainly a foliar pathogen, although postharvest storage rots also occur. ACIAR, 2008 describes the disease:

> A small, circular speck, brown on the upper surface of the leaf and water-soaked below, is the first sign of the disease. Infections often begin on the lobes and sides of the leaf where water collects. The spots enlarge, become irregular in shape, and are dark brown with yellow margins. Initial spots give rise to secondary infections and, soon afterwards, the leaf blade collapses and dies. Spores are produced at night and can be seen around the spots in the morning. Clear, yellow-to-red droplets ooze from the spots and develop into dark brown, hard pellets as they dry. This is a characteristic of the disease. Spores may be trapped inside the pellets. Usually, petioles are not attacked, but instead collapse as the leaf blade is destroyed. However, in American Samoa and Samoa, petiole infection is common as the taro varieties are very susceptible to the disease. The fungus can also cause a postharvest corm rot that is difficult to detect unless corms are cut open. The rots are light brown and hard (Carmichael *et.al.,* 2008, p. 30).

Plate 1 Symptoms of *Phytophthora colocasiae*



Source: ACIAR**,** 2008, p. 31

The disease significantly reduces the number of functional leaves and can lead to yield reductions of the magnitude of 50 per cent (Trujillo, 1967; Jackson, 1999). Inoculum in the form of spores is spread by wind-driven rain and dew to adjacent plants and nearby plantations. The disease can also be spread on taro planting material and the fungus has been reported as remaining alive on planting tops for about three weeks after harvest (Jackson, 1999). This is the most likely source of the pathogen in new countries and the means for its rapid spread within a country, once established. Therefore, strict quarantine measures are required as a first line of defence against the disease. In addition to corm yield losses due to the reduced leaf area in diseased plants, there is also a corm rot caused by *P. colocasiae.* This is mainly a problem when taro corms are stored for more than seven days but not in subsistence economies where corms are harvested and consumed within days.

The host range of TLB is limited to *Colocasia* taro. *Xanthosoma* taro is immune. While *Alocasia* taro can be infected by the pathogen, there is little inoculum produced and therefore, little likelihood of an epidemic on this host (Brunt *et.al,* 2001).

Climate and TLB

A number of studies have examined the relationship between the spread of TLB, temperature and relative humidity (CABI, Trujillo,1965 and Putter, 1976). The impact of night temperature on relative humidity would appear to be the key factor in the rapid spread of the disease5. Putter (1976), working in PNG, found that temperature and relative humidity together explained 72.57 per cent of the variation in sporulation, with all these associations being highly significant (P<01).Trujillo (1965) showed that a minimum night time temperature of 21^{o}C and a relative humidity of 100 per cent provided optimum conditions for the TLB. With RH less than 90 per cent, no sporulation occurs and zoospores rapidly lost their viability.

Climate change has implications for countries that already have the disease and for those who currently do not. Higher altitude areas of PNG, where temperatures are currently outside the optimum range for sporulation at night will warm and the incidence of the disease will increase. The same will occur in PICs further away from the equator where taro is grown and currently do not have the disease, such as Fiji, Tonga, and Vanuatu. These countries located further away from the equator have seasonal climates which currently would slow disease development. Climate change will mean that they will become more vulnerable. In these countries, spread would be a factor of rainfall, as it is in countries where epidemics now occur.

TLB in the Pacific islands[6]

Taro leaf blight (*Phytophthora colocasiae*) is found in American Samoa; Federated States of Micronesia; Guam; Northern Mariana Islands; Palau; PNG; Samoa; and the Solomon Islands; but is not found in Fiji, Tonga, Cook Islands and Vanuatu.

Jackson (1996) notes that, where TLB has occurred in the region, many growers have been forced to abandon taro and to rely on other root crops. This has been particularly the case in PNG and the Solomon Islands. Samoa was able to eventually prove to be an exception through a taro-breeding programme that introduced tolerant and resistant germplasm.

Brunt *et.al* (2001) report the earliest records for the appearance of TLB in the Pacific islands are in Guam (1918) and Hawai'i (1920). The disease appeared in the southern Solomon Islands and PNG a couple decades later. Trujillo (1996) reports that prior to the arrival of TLB, 350 different taro varieties were known in Hawai'i. The total number of identified varieties found today in Hawai'i is less than 40. In Guam, where the disease has been present for a longer period than Hawai'i, the disease is now considered unimportant for the TLB tolerant varieties that remain. As is the case with Samoa, most of the present varieties in Guam have been introduced (Wall, 1996).

TLB is now present throughout Micronesia and is thought to have been introduced during the period of Japanese occupation following WW1 (Brunt, 2001). On Pohnpei,

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[5] Putter (1976) found that temperature and relative humidity together explained 72.57 per cent of the variation in sporulation, with all these associations being highly significant (P<01).
[6] This section draws heavily on Brunt *et.al,* 2001.

the majority of the taro varieties that existed before the arrival of the Japanese have gone (Trujillo, 1996) and leaf blight has been responsible for the serious decline in taro as a food crop (Raynor and Silbanus, 1993). The present Micronesian lines probably originated from Japan and were introduced when the local germplasm was wiped out by TLB (Grahame Jackson per.com. Sept, 2011).

On Pohnpei, taro now ranks behind yams, banana, imported rice and breadfruit as a staple crop (Raynor and Silbanus, 1993). TLB is present in Palau but it is not regarded as a major problem by farmers due to the high degree of resistance displayed by most Palauan varieties (Ngiralmau and Bishop, 1991). Four FSM varieties were first introduced into Samoa after the arrival of TLB, followed by 14 Palauan varieties introduced via Hawai'i. These introductions gave some initial respite to the ravages of TLB.

It is thought that TLB spread to PNG from Southeast Asia through Indonesia during WWII (Kokoa, 1996). The disease has been identified as a major contributing factor to the overall decline in the importance of taro as a food staple in PNG. On this basis alone, the consequence of the disease has been immense. Bourke and Harwood (2009) note that the first major change to PNG agriculture since 1940 was the replacement of taro by sweet potato as the staple in Bougainville and other lowland locations. This significant change was a direct consequence of TLB. Prior to the introduction of sweet potato, *Colocasia*taro provided an estimated half of PNG food energy from staple foods – it now contributes only about four per cent (Bourke and Harwood 2009, p. 197). Connell (1978) describes the devastating impact TLB had on Bougainville food production and culture in the immediate post war period:

> Until around the end of World War II, the root crop taro (*Colocasia esculenta*) was by far the most important food crop throughout the whole of Bougainville Island. The Siwai area of south Bougainville was quite typical; as Oliver recorded:
>
> *Taro occupies so prominent a place in Siwai life that one might go on for pages, describing the numerous varieties grown; the exact details of their planting, weeding and harvesting; the high value placed upon it as a vegetable food; the feelings of deprivation natives expressed when they must go without it; the frequency that it enters into conversation; the numerous metaphors for it and its use in ritual……Siwai natives spend more hours growing taro than any other enterprises, that the plant occupies 80 percent of their diet, and that it is at the basis their subsistence economy generally (Oliver, 1955, p.26).*
>
> Taro (as a result of TLB) had almost completely disappeared as a food crop there and elsewhere in Bougainville whilst sweet potato *(Ipomoea batatas*), hitherto of minor importance throughout the island, had taken its place as the most prominent food crop although, it never took the place of taro in island culture.

Putter (1993) reports that taro leaf blight on Bougainville resulted in the deaths of about 3000 people. Although, the coincidence of the spread of TLB in Bougainville with WWII makes it difficult to attribute any given change solely to the effects of leaf blight (Packard, 1975). Jackson (1996) reports a number of subsequent severe TLB epidemics in PNG as the disease spread - Manus in 1976 and Milne Bay in 1988.

From Bougainville, TLB spread to the Solomon Islands where it was first reported in the Shortland islands in 1946 (Liloqula *et. al,* 1996). Over the ensuing years, TLB spread to most of the provinces as a result of the increased movement of people and produce in the postwar years. Taro cultivation declined quite drastically in the Solomons and as per PNG, it has been replaced by sweet potato. Taro production has also been affected by declining soil fertility associated with more intensive land use, virus infection and the damage caused by papuana beetle.

TLB in Samoa

Taro leaf blight was first detected on Tutuila island, American Samoa, 15 June, 1993 (Brunt *et.al,* 2001). In less than one month, taro leaf blight was diagnosed and confirmed in Samoa. It was first observed on the island of Upolu at Aufaga Aleipata and two days later from Saanapu and adjacent districts of Alafou, Samusu, Utufaalalafa, Malaela, and Lepa. According to Chan *et.al*(1998), it is generally believed that TLB entered Samoa via unauthorised imports of infected corms of planting material (p. 94).Hunter *et. al*(1998) describes the specific circumstances of the rapid spread of leaf blight in Samoa:

> It is believed that the rapid spread of the disease was encouraged by the movement of infected planting materials around the two main islands, Upolu and Savai'i. At this time, there was a major replanting of taro underway in the aftermath of Cyclone Val and anything up to 10,000 plants could be planted by a single farmer in a one week period (Semisi, 1993). Various factors contributed to the rapid spread of the disease in Samoa. The area planted to *taro Niue* at the time was extremely large and effectively ensured a monocrop situation, comprising a highly susceptible variety. There was a continuous and abundant source of taro for the disease because of the practice of many farmers to interplant on old plantations and stagger their cultivation. Combined with the movement of planting material and the ideal weather conditions that exist in Samoa for the disease, it is not surprising that the disease reached epidemic proportions.

Graham Jackson, former Technical Director of the TaroGen Project, believes that the movement of planting material is not sufficient to explain such a rapid spread of TLB throughout Samoa. He suggests that winds, at times of exceptionally high relative humidity have been a major contributing factor (pers. comm. May, 2011). The weather conditions during the July-August of 1993 were unseasonably wet (Chan *et.al* 1993, p. 94). PNG Agriculture authority, Mike Bourke, in commenting on an earlier version of this report noted "When I visited Samoa in 1981, it struck me that, if/when TLB got to Samoa, it would cause severe damage as the rainfall/temperature were similar to the New Guinea islands". His prediction proved correct.

During the period 1980-1993, taro exports grew rapidly in Samoa and became the country's largest export earner – only to be interrupted by Cyclone Val in 2000 (figure 6). It has been surmised that the more intensive monoculture taro cultivation with fewer rotations associated with the export boom made Samoan taro more susceptible to diseases, such as TLB (Chan *et.al,* 1998).

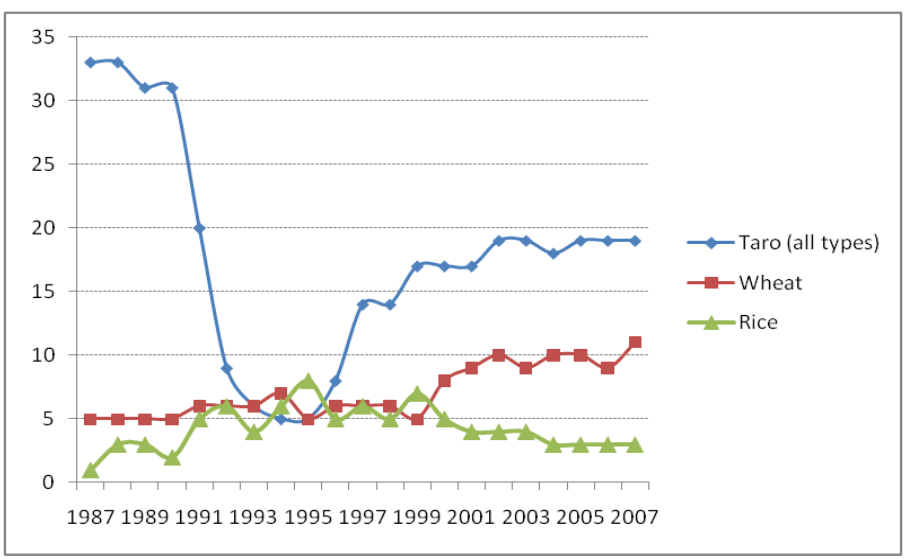
The food security and economic impact of taro leaf blight in Samoa

Impact of domestic consumption

Prior to 1993, taro was by far the most important food staple in Samoa. At the time, over 90 per cent of taro production was used to meet household consumption needs (Chan *et.al.*1999, p. 93). According to the 1989 Agricultural Census, 96 per cent of agricultural households grew *Colocasia* taro of which 76 per cent were grown as a monoculture. The Census showed that 62 per cent grew taro for mainly home consumption; 35 per cent grew taro, partly for home consumption and partly for sale; and 3 per cent grew taro mainly for sale (Ministry of Agriculture 1990 p, 48). There were 16,000 hectares planted with taro, compared with only 3,600 hectares planted with ta'amu (*Alocasia macrorrhiza*), and 2,500 ha with bananas (Ministry of Agriculture 1990, p. 55). According to a detailed nutritional survey conducted in 1991, taro made by far the largest contribution to total carbohydrate intake. It was estimated that taro accounted for 19 per cent of CHO intake followed by bananas (12 per cent), breadfruit (8 per cent) (Galanis 1995, p. 170). At that time, rice was only of minor importance, accounting for only 3 per cent of CHO intake.

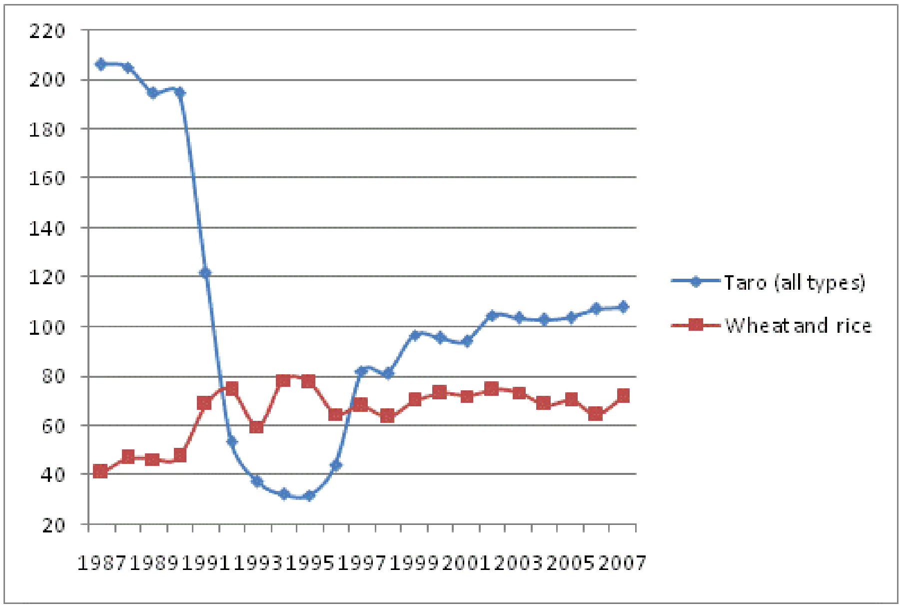
The FAO Food Balance Sheet (1989)shows that 19,460 tonnes of taro (which included ta'amu and taro palangi (*Xanthosoma* taro), were consumed for food (figure 9). This represented 194.6kgs taro/person/day, which provided 422 kcal/person/day (figures 10 and 11). The same Food Balance Sheet shows that in 1989 Samoan's consumed only approximately 5,000 tonnes of imported wheat and 3,000 tonnes of imported rice (figure 9). This represented 46.6 kgs per capita of wheat and rice combined which provided 383 kcal/person/day (figures 10 and 11). Taro, and in particular *Colocasia* taro, was by far the dominant food staple in Samoa.

Figure 9 Samoan total consumption of taro, wheat and rice, 1987 to 2007 (1,000 tonnes)*



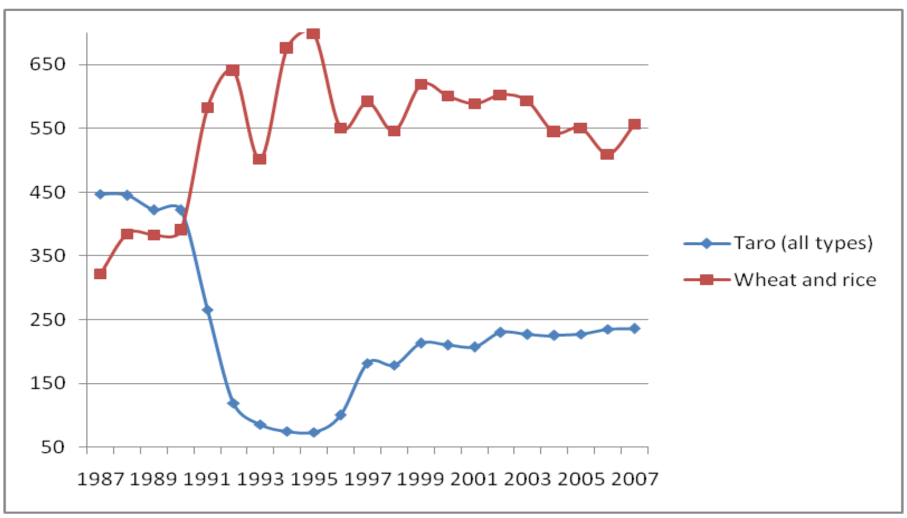
* FAO Food Balance Sheets for Samoa

Figure 10 Samoan per capita consumption of taro, wheat and rice, 1987 to 2007 (kg/pers/year)*



*FAO Food Balance Sheets for Samoa

Figure 11 Samoan per capita consumption of taro, wheat and rice, 1987 to 2007 (kcal/pers/day)*



*FAO Food Balance Sheets for Samoa

Food Balance Sheet data show the dramatic impact that TLB had on taro production and consumption. A severe cyclone in 1991, Cyclone Val, had already adversely affected local food production and the resulting food aid had encouraged a marked increase in rice and wheat imports that were never to be reversed (Galanis*et.al*, 1995).

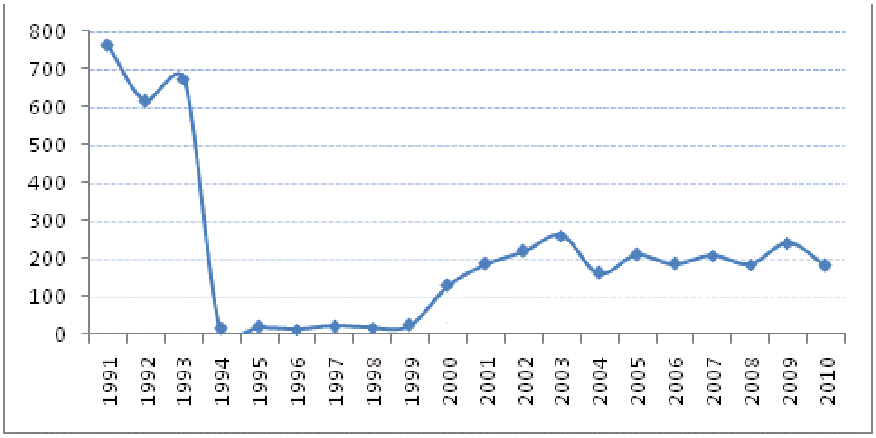
The Food Balance Sheets show that taro (all types) consumption bottomed out at approximately 5,000 tonnes in 1994, compared with an average 32,000 tonnes for 1987 through 1990. In 1994, 7,000tonnes of wheat and 6,000tonnes of rice were consumed, compared with an average of five tonnes of wheat and three tonnes of rice for 1987 through 1990.

The impact of TLB on taro production can also be gleaned for the availability of taro on the Fugalei market (Apia's main produce market) (Figure 12). From the Central Bank of Samoa Fugalei Market Surveys, it is estimated that an annual average of around 700 tonnes was available for sale on Friday at the market for the few years prior to the arrival of TLB. Friday is by far the most important marketing day for farmers. Assuming approximately half the taro that enters the market is supplied on a Friday, the estimated average annual supply to the market over that period is 1,400 tonnes. The estimated average price paid for taro over this period was WST1.11/kg, WST 1,100 /tonne (Figure 13). Thus, the estimated annual value of taro sold of the Fugalei market prior to the arrival of TLB was WST 1.6 million.

The amount of taro sold is only a fraction of the total volume of taro consumed. The FAO Food Balance Sheets provide an insight into the amount of taro that is actually consumed. Unfortunately, the Food Balance Sheet includes all types of taro (*Colocasia, Xanthosoma* and *Alocasia*) in the other roots category[7]. Prior to TLB, the other roots category would have been made largely of *Colocasia* taro. A detailed nutritional survey conducted in 1991 estimated that the averaged adult consumed 15.4 pieces of taro a week (with an s.d.of5.3 pieces) (Galanis*et.al*, 1995 p. 169). Based on an estimated 10 pieces per taro corm, the average adult was consuming 1.5 taro corm per week or 145 corms per year. The weight of the average taro Niue corm would be about 1.5 kgs. Thus, the average adult was consuming around 110kgs (s.d.37 kgs) of taro a year. At that time, there were 98,500 people over the age of 14 (61 per cent of the population) living in Samoa. On this basis, the adult population would have consumed around 11,000 tonnes. To this has to be added the taro consumption of those less than 15 years. Thus, it is estimated that total annual taro consumption was of the order of 15,000 tonnes, with a standard deviation of 5 tonnes. These estimates are consistent with the Food Balance Sheet Data. The value of this taro was around WST 16.5 million based on Fugalei market prices at the time.

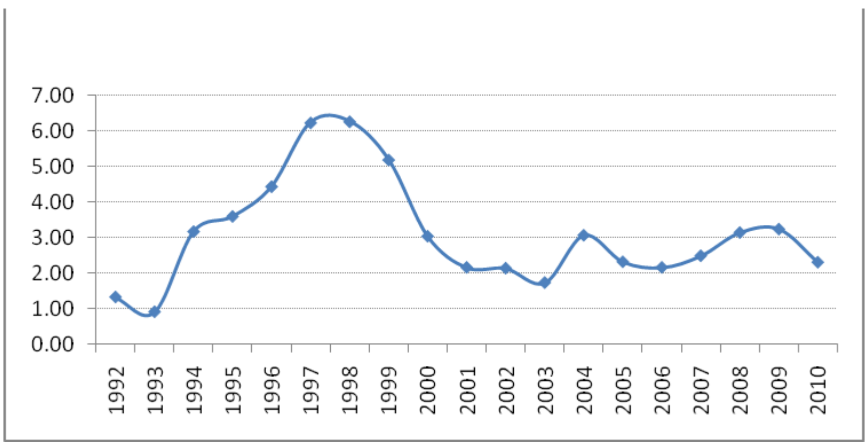
[7] The FAO Food Balance Sheets follow a standard format for all countries. For root crops, there are the following categories: cassava, potatoes, sweet potatoes, yams, and other roots. For Samoa, all taro varieties (*colocasia, xanthosoma* and *Alocasia)* make up the other roots category.

Figure 12 Estimated annual volume of taro available on Fridays at the Fugalei market (tonnes)*



* Derived from data supplied by the Central Bank of Samoa, Fugalei Market Survey

Figure 13 Average price for taro sold at the Fugalei market (tala/kg)*



* Derived from data supplied by the Central Bank of Samoa, Fugalei Market Survey

For the first five or six years following the arrival of TLB, there was little taro consumed in Samoa. The 1989 Agricultural Census showed that 100 per cent of households consumed taro on a weekly basis (Ministry of Agriculture, 1990, p. 48). The 1999 Agricultural Census only had 23.8 per cent of households consuming taro on a weekly basis. In comparison, the consumption of other staples increased markedly, compared with 1989 where77.9 per cent of households consumed bananas on a weekly basis, 41.5 per cent consumed taro palagi, and 65.7 per cent consumed tam'mu (Ministry of Agriculture, 2000, p. 33). The 1999 Agricultural Census showed 4,700 hectares planted with taro and taro palagi combined (p. 35).

This compares with 16,000 ha planted with taro in 1989. The area planted with tam'mu in 1999 was 5,300 ha, up from 3,600 ha in 1989. The increase in taro palagi and tam'mu planting as reflected in the FAO Food Balance Sheet for Samoa shows a strong recovery in the other roots category (which is essentially all three types of taro grown in Samoa) after 1997.

The low level of taro consumption is reflected in the small volume of taro entering the Fugalei market (figure 12). It is estimated for the years 1994 through 1999a total of only around 230 tonnes was sold on the Fugalei market. This represents less than 40 tonnes sold annually, compared with the estimated 1,400 tonnes sold annually for the years 1991 through 1993. The amount sold on the market was less than three per cent of pre-TLB sales. The little taro that was available on the market fetched exceptionally high prices – the average market price in 1998 and 1999 exceeded WST 6/kg (figure 13).

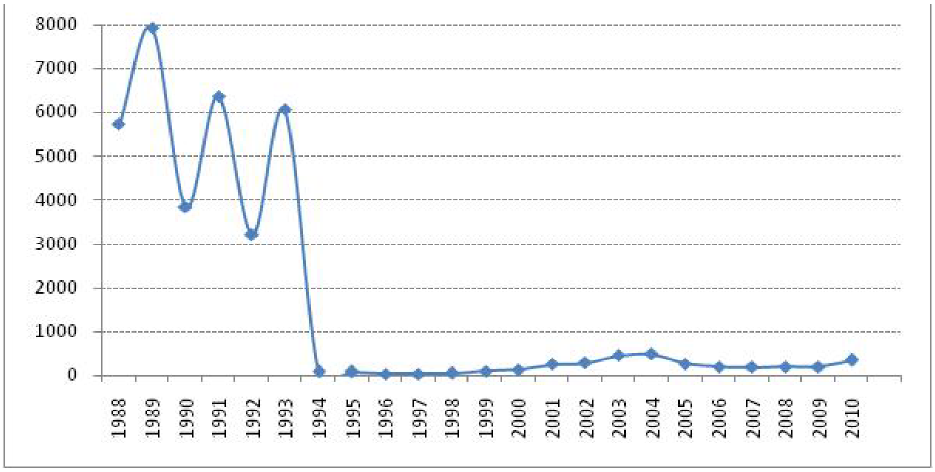
It is estimated that less than 500 tonnes of taro were consumed annually for the years 1994 through 1999 – this was based on taking the Fugalei market's three per cent of pre-TLB sales as a proxy for the overall availability of taro for the entire country. The estimated annual tala value for this loss of production is put at approximately WST 16 million, based on the average Fugalei market prices prior to the arrival of TLB.

From 2000 onwards, there was some increase in the volume of taro available on the Fugalei market as the blight tolerant varieties began to become available (figure 12). However, supply is yet to recover above 25 per cent of the pre-TLB levels. The increase in taro production and consumption after 2000 is reflected in the Ministry of Agriculture and Fisheries (MAF) Agricultural Surveys and in the FAO Food Balance Sheets for Samoa.

Impact on taro exports

Taro leaf blight meant that Samoa not only lost its main food crop, but also its main export earner. In 1993, Samoa's taro exports to New Zealand stood at 6,300 tonnes (fob value WST9.5 million) (figures 14 and 15). This represented 60 per cent of the value of Samoa's exports in that year. The largest volume of exports was 7,800 tonnes which occurred in 1989 (Central Bank of Samoa 1999). Mirroring the situation on the Fugalei market, there were virtually no exports for the six years following the arrival of TLB (figure 14). From 2000 onwards, there has been a small recovery in taro exports. However, these exports have yet to exceed 500 tonnes and in 2010, stood at only 330 tonnes.

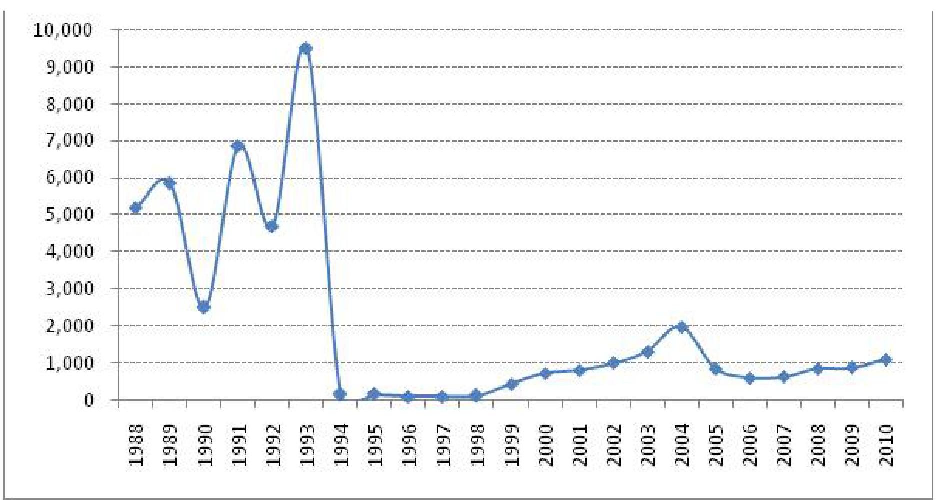
Figure 14 Samoan taro exports (tonnes)*



*Source: Central Bank of Samoa Statistics

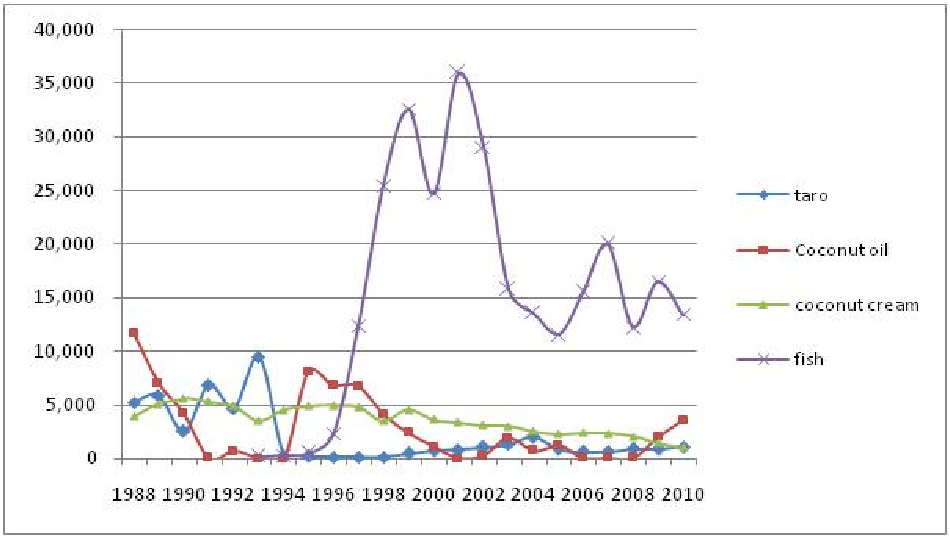
In 1993,the value of taro exports was WST 9.5 million, making it by far Samoa's largest export earner. The next largest export earner was coconut cream, valued at WST 3.5 million in 1992 (figure 16). For the next six years, the value of Samoa's annual taro exports did not exceed WST 500,000. Thus, the annual loss of export earnings was some WST 9 million. Fortunately for the Samoan economy from 1997 onwards, fresh tuna export was more than able to fill the vacuum left by taro (figure 16).

Figure 15 Value of Samoa's taro exports ('000 tala)



*Source: Central Bank of Samoa Statistics

Figure 16 Samoa main export earners ('000 tala)



*Source: Central Bank of Samoa Statistics

Assessing the overall total impact of taro leaf blight

Quantifiable impacts

For the first six years following the establishment of TLB in Samoa, the annual losses is estimated at WST 25 million. This is made up of the following components calculated above.

- **Domestic taro consumption** WST 16 million – based on pre-TLB Fugalei Market prices.
- **Taro export** WST 9 million – based on pre-TLB fob export prices.

Since 2000, the annual losses attributed to TLB have declined due to the modest recovery in domestic taro production and the recommencement of a small level of taro exports.

Consequences that are not readily quantifiable

Adverse nutritional impacts

Adverse impacts resulting from TLB that are not readily quantifiable need to be added to quantifiable losses. The most important of these have been the negative nutritional consequences. With the loss of taro corms came the loss of taro leaves (*laulu'au*). Taro leaves are a major part of Samoan diet via *palusami* (taro leaves cooked in coconut cream). Taro leaves are a rich source of folic acid and other vitamins and minerals, particularly potassium and β-carotene equivalent (USP/FAO and Christine Quested, Nutrition Section of Mininstry of Health). For at least two years after the arrival, there was very little *palusami* available. There was some substitution with the less preferred xanthosoma (taro palagi) for the manufacture of *palusami.*

There was significant substitution for taro from traditional staples (banana, breadfruit, ta'amu and yams, etc.) in the Samoan diet. The nutritional impact of this substitution was by and large neutral, other than the loss of *palusami* for several years. However, a greater degree of carbohydrate substitution in the Samoan diet came in the form of imported wheat and rice (figures 9, 10 and 11). A shift toward imported grains was already apparent before TLB decimated the taro crop (figure 9). A detailed nutritional survey conducted in early 1991, just prior to Cyclone Val found that rice accounted for only three per cent of Samoan carbohydrate consumption (Galanis et.al. 1995, p. 170). Immediately after the cyclone, a substantial volume of rice was imported as part of the cyclone relief programme. Some eight months after the cyclone and well after the imported food aid had been consumed and most crops rehabilitated, rice's share of carbohydrate consumption for the survey sample had risen to nine per cent (a threefold increase). Since that time, wheat and rice imports have continued to outstrip Samoa's population growth (figure 10). The loss of taro in 1993 saw an acceleration in grain imports, which has yet to be reversed and is probably, unlikely to. The substitution of white polished rice and white flour for more nutritious traditional staples can be expected to have nutritional consequences for the Samoan community. It also has significant economic consequences in terms of loss of foreign exchange and increased food security vulnerability.

Adjustments in Samoa's traditional cropping systems

Apart from the increase in imported grain substitution, there was significant substitution of other traditional staples for taro following TLB thus, lessening the extent of the overall impact of the disaster. Paulson and Rogers (1997) described the adjustments that took place in the agricultural sector after taro leaf blight destroyed the taro crop.

> By June 1995, two years after the taro leaf blight first appeared in Western Samoa, the taro zone in the two main villages had been almost completely abandoned and was under fallow vegetation. Most households had redirected their efforts to the area nearest the village. This area of old gardens, secondary growth and senile coconuts had been transformed into well-tended mixed gardens producing a variety of food and tree crops. All gardens had several varieties of banana and at least two varieties of ta'amu (*Alocasia macrorrhiza*). Most had yams, cassava, and several varieties of breadfruit, and a variety of minor crops and useful plants. Most farmers were intercropping coconut and cocoa seedlings in the mixed gardens. There was much experimentation, with land managers visiting each others' gardens for ideas (p. 177).

The strength of Samoa's traditional farming system did much to avert a catastrophic disaster. This could have been, perhaps, equivalent to the impact of the blight that destroyed the Irish potato crop in the mid-19th Century that caused the Great Irish Famine, or the starvation that accompanied the arrival of TLB in Bougainville just after WW2.

It is unfortunate that throughout the Pacific islands, the economic value of traditional food production tends not to be well recognized by agricultural and national planners and is usually much under-estimated in national accounts. This has had a distorting effect on agriculture policies and their implementation. For example, Paulson and Rogers noted that key Department of Agriculture officers in Samoa were not impressed by the diverse mixed gardens of traditional food crops that sprung up after the blight.

These officials ‘held a vision of a more export-orientated, commercialized agricultural system modelled on those of industrialized countries’ (Paulson and Rogers, 1997 p. 182).

Offsetting benefits to other Pacific island countries

Taro leaf blight has resulted in substantial losses to Samoa in terms of food security, nutrition, farmer income, export earnings and balance of payments. However, there were offsetting benefits to other Pacific island countries, particularly Fiji who has now largely taken over Samoa’s export market. Prior to 1994, Fiji was a minor taro exporter. Taro is now Fiji’s largest agricultural export earner after sugar. Fiji’s annual taro export volume over the last few years has hovered around 10,000 tonnes (fob value FJD 19 – 20 million), with about 65 per cent going to New Zealand and the balance to Australia and the USA. Nearly 70 per cent of Fiji taro exports originate from the island of Taveuni.

The taro from Taveuni is the pink fleshed *Tausala ni Samoa* variety. Tausala is virtually identical to Taro Niue, the favoured traditional Samoa cultivar that was decimated by TLB[8]. This variety is strongly favoured by the Samoan communities living in the target markets of New Zealand, Australia and the United States. Taveuni’s taro exports have stagnated in recent years because of declining productivity, increasing production costs and market access problems with exports to Australia and New Zealand. The taro monoculture on Taveuni, built around an almost genetically identical variety to taro Niue, is highly vulnerable to being annihilated in the future by TLB as minimum night time temperatures rise with climate change.

The public policy and investment response to TLB

Short-term adaptation response with existing taro varieties

Initial efforts to minimise the impact of the disease

Spraying, quarantine and public awareness

Early efforts to contain taro leaf blight in Samoa focused on the spraying of infected plantings with the fungicides[9]. This approach was actively promoted by the AusAID funded Western Samoa Farming Systems Project that ran until 1997. Initially, fungicide spraying was undertaken by Ministry of Agriculture staff. Later, fungicides were supplied free to farmers through village *pulenuu*(village mayors) and application equipment was made available at subsidized prices at the government-owned Agricultural Store (Chan, 1996). The cost of the initial spraying programme was WST$600,000 (Chan, 1996). Spraying proved ineffective and, despite heavy subsidization of the cost for fungicides, most farmers who grew taro traditionally were not inclined to incur the extra costs of

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[8] The ‘Talo Niue’ collected from Samoa and ‘Tausala ni Samoa’ from Fiji were DNA fingerprinted by University of Queensland under then TaroGEN project and found out to be different by only one band of DNA (pers, comm. , Valerie S. Tuia).

[9] The main fungicides used were the systemic fungicides Ridomil and Manzate.

fungicides or to apply the additional labour required for spraying and supporting sanitation measures (Brunt *et.al*, 2001, p. 7).

There were also quarantine measures put into place to minimise the movement of planting material, leaves and soil. This was supported by a public awareness campaign. These were to no avail. Brunt *et.al* note that the unseasonal wet weather in the months following the introduction of the disease into Samoa and the fact that planting material was still being routinely moved meant the disease spread rapidly (p. 7).

Cultural control

From the experience in Hawai'i and elsewhere, various cultural methods were recommended for the control of taro leaf blight. These measures included the removal of infected leaves and wider plant spacing. Other cultural methods that were recommended include delaying planting on the same land for a minimum of three weeks, avoiding plantings close to older infected ones and preventing the carryover of corms or suckers which can harbour the pathogen from one crop to the next(Jackson, 1999). In Samoa, such cultural control measures were found to have negligible effect where the conditions favoured disease development (Brunt *et.al.).*

Taro Niue in Samoa today

The failure of spraying and cultural control measures means that very little *taro Niue*are grown in Samoa now. The production of this still-preferred variety is confined to a few dedicated farmers who strictly adhere to the required spraying programme and cultural practices. The significant extra cost and effort required is justified by the price premium and the prestige they have from having *taro Niue*.

A longer term response through introducing, selecting and breeding TLB tolerant and resistant varieties

When it became clear that *taro Niue* could no longer be economically grown by most growers in the presence of TLB, attention turned away from the adaptation of the existing varieties to the disease. The focus first moved to introducing and selecting exotic resistant varieties. After achieving some initial success with exotic varieties, the long-term process of taro breeding was added to the programme. The challenge was not only to find resistance but, also to meet the demanding taste requirements of Samoan communities at home and abroad, and to provide for a shelf life that would allow export by sea. The challenge was met, using a classical plant breeding approach which incorporated a high level of grower participation.

The narrow gene pool of Pacific islands taro: The need to introduce exotic varieties

Traditional Pacific island crops are particularly vulnerable to disease due to their narrow genetic base. This makes root crops particularly susceptible to the impact of diseases brought about by the impact of climate change such as TLB.

Immediately after the outbreak of TLB in 1993, a high level Samoan delegation went to Pohnpei to try out, literally to taste, the taro growing there. As a result of this visit, the first exotic varieties were imported by the Samoan Ministry of Agriculture from the Federated States of Micronesia (FSM). These FSM varieties were first released to growers in 1996/97.

In 1994, through the Tissue Culture Unit of the University of the South Pacific (USP)'s Alafua Campus, Samoa embarked on a programme to screen and evaluate exotic taro varieties. A recorded preliminary trial demonstrated that disease severity differed for each variety. Initially, four varieties, originating from the Federated States of Micronesia (FSM)[10] and the Philippines[11], were found to be more resistant to TLB. These four varieties were further multiplied and evaluated in trials during 1996–1998. From these trials, the Philippines variety, known locally as taro *Fili,* proved to be most satisfactory in terms of TLB resistance and dry matter content (Brunt *et.al*, 2001 and Iosefa and Rogers, 1999)[12]. It was promoted to farmers by the Ministry of Agriculture, where it received a high level of acceptance. Introductions from Palau followed, which showed good levels of resistance against taro leaf blight in Samoa.

Prior to the commencement of a taro breeding programme, taro *Fili* and some of the Palauan introductions, made an important contribution to getting taro reintroduced to the Samoan farmers cropping systems. These introductions were instrumental in getting nutritious *palusami* back onto the dinner table of Samoan households. However, the release of a few introduced varieties was not sufficient to meet the needs of the growers. The shortcomings of taro *Fili*, the first introduced variety that was actively promoted by the Ministry of Agriculture, were: relative susceptibility to TLB (especially in wetter areas); low yields; and poor storability (Hunter *et.al,* 2007). Also, although it had the right firmness and taste when boiled, it was said to develop too hard a texture when baked in the umu. It had become clear that a more concerted effort requiring a far larger number of accessions combined with a breeding programme that selected particular attributes, would be necessary to have a substantial sustainable impact.

A breeding programme to broaden the taro gene pool: complementary regional and national programme

The Samoa taro breeding involved the development of complementary regional and national programmes. These were the Secretariat of the Pacific Community (SPC)Taro Genetic Resources: Conservation and Utilisation (TaroGen) and USP (Alafua)'s Taro Improvement Project (TIP).

TaroGen

The impact of taro leaf blight on Samoa, the subsequent loss of taro genetic resources, and the continuing vulnerability of other Pacific island countries to the disease was the major impetus behind the development of the regional project: Taro Genetic Resources: Conservation and Utilisation (TaroGen). The disastrous consequences of TLB, was the

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[10]Pwetepwet, Pastora and Toantal from FSM.
[11]PSB-G2from the Philippines Seed Board.
[12]Samoans prefer dry, firm-textured taro and therefore, per cent dry weight is one measure of eating quality. Dry matter content ofPSB-G2 was 37 per cent (Brunt et.al 2001).

catalyst that eventually focused the minds of policymakers and donor agencies, at a time before climate change adaptation had become a priority for donor agencies.

Yet, despite the gravity of the situation, it still took five years before a coordinated regional effort would commence implementation. Initially, there was a lack of understanding as to the severity of the disease and the general consensus was that the problem would be over within a year (per. com Grahame Jackson). This was compounded by technical advice from other projects that were promoting cultural control methods and the use of fungicides as appropriate control measures.

The five-year AusAID funded TaroGen Project finally began in 1998. The Project supported taro breeding programmes in PNG and Samoa. The objective of these breeding programmes was to provide growers with improved varieties to overcome production constraints, in particular TLB. Taro collecting and characterization in Polynesia and Melanesia was supported together with the investigation of various *ex-situ* and *in-situ* taro germplasm conservation strategies. The TaroGen project supported the Tissue Culture Specialist and Team Leader based at SPC, Fiji and the services of a part-time breeder/pathologist based at the USP (Alafua) Campus. These people proved key to the successful laying of the foundations of the taro breeding programme ground work and for the work that was to follow.

Three other agencies made important collaborative inputs in the TaroGen Project. These were the International Plant Genetic Resources Institute (IPGRI, now Biodiversity International), the Australian Centre for International Agricultural Research (ACIAR) and the Horticulture and Food Research Institute of New Zealand, Ltd. (HortResearch). IPGRI assisted with the rationalisation of collections and identification of core sub-sets for each country collection[13]. ACIAR, through University of Queensland (UQ), funded DNA fingerprinting and the virus-testing components. ACIAR also funded the Queensland University of Technology (QUT) to develop methods for diagnosis and detection of taro viruses. This work enabled the safe international movement of taro germplasm. HortResearch was funded by the New Zealand Ministry of Foreign Affairs and Trade to develop methods to assess leaf blight resistance in populations of progeny for the taro breeding programme.

The major outcomes of the TaroGen Project are[14]:

- The establishment of the Regional Germplasm Centre, which is now known as the Centre for Pacific Crops and Trees (CePaCT), SPC-Suva (Plate 2).
- The TaroGen project supported the collection of over 2200 accessions of taro, of which CePaCT holds about 469 in the gene bank.

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[13]TaroGen collected more than 2,200 different accessions (or samples) of taro from across the Pacific region. This large number needed to be reduced to a more manageable core collection. A core collection contains the maximum amount of genetic diversity within the smallest number of samples. This makes long-term conservation much more feasible, particularly where resources are limited. Also, with core collections well characterised, this promotes use and exchange (per com Mary Taylor). The more than 2,200 accessions have been reduced to a core collection of 196 which are housed at CePaCT.

[14] Information provided by SPC's CePaCT Director Dr Mary Taylor

Plate 2 The CePaCT taro tissue culture collection at SPC- Suva.

- The existence of CePaCT made it possible for the region to have access to taro from Southeast Asia. A total of 120 accessions came from the EU-funded Taro Network for Southeast Asia and Oceania (TANSAO). These accessions have been distributed to countries on request. The USP Alafua taro breeding programme evaluated many of these accessions and 16 have been incorporated into their taro breeding programme.
- The CePaCT not only conserves taro but, has been a conduit for importing germplasm into the region. Through CePaCT, salt and drought tolerant sweet potatoes have been imported from the International Potato Centre (CIP) in Peru, multiplied in CePaCT and distributed to other countries in the region.
- The CePaCT is now establishing and evaluating a climate-ready collection (crops and varieties with tolerances to climatic traits) – it has a very important role in getting this material to countries and eventually to the farmers.
- Two masters and one PhD have been completed under CePaCT. It is currently supporting four Masters students.
- The taro breeding programme has continued through the support of SPC and more lately through USP Alafua through the full-time employment of taro breeder Iosefa Tolo.
- These new taro lines have, to date, mainly been to the benefit of Samoa. However, selections have been sent to virtually all other regional countries - American Samoa, Cooks, Fiji, FSM, Guam, Kiribati, Marshall Islands, Nauru, Norfolk Islands, North Marianas, Palau, PNG, Solomon Islands, Tokelau, Tonga, Wallis & Futuna.
- Through the ACIAR-funded component, virus indexing methodology was established and this technology is now being used by the CePaCT to safely distribute the Samoa breeding lines to other countries.
- Benefits have now spread beyond the region. CePaCT have dispatched ten lines from the Samoa breeding programme to the International Institute of Tropical Agriculture (IITA), Nigeria to support farmers in that part of the world in battling TLB.

- The region is benefiting from the expertise and experience of taro breeder, Iosefa Tolo who is employed full time by USP Alafua. He is now actively involved in capacity-building work in the region.
- The CePaCT and the Plant Genetic Resources (PGR) network (PAPGREN) are used by PGR-focused donors to facilitate region-wide programmes.

The CePaCT provides a mechanism by which countries can conserve and, at the same time, take advantage of germplasm from elsewhere, as is well illustrated by the Samoa case study. The TLB-resistant lines selected from the Samoa breeding programme are now available to other countries in the Pacific, as well as globally, as shown by the distribution to IITA in Nigeria. Further, so too are the results of the germplasm evaluation in Samoa, and the germplasm itself for any countries who wish to embark on their own breeding programme.

USP (Alafua)'s taro breeding programme

The first cycle of taro breeding (Cycle One) was initiated by Param Sivan in 1997, prior to the start-up of TaroGen.

Cycle One combined some Micronesian lines, with PSB-G2 from the Philippines and some Samoan lines. The second cycle included varieties from Palau and combined these with varieties from Cycle One. In Cycle Three, taro Niue was reintroduced into the breeding cycle because of the importance of this variety for domestic and export markets. Yet, the progeny from the top Cycle Three clones showed few taro Niue traits, probably due to the susceptibility of TLB in lines with taro Niue parentage (SPC Land Resources News Letter, April, 2009). However, because of the importance of taro Niue, some of these susceptible lines were still included in later crosses. Cycle Four consisted of crossing Cycle Three lines. Field observation showed that the progeny from these crosses were very uniform in their characteristics, indicating the breeding programme had reached a genetic ceiling. Further progress could only be achieved therefore, with infusion of material from outside the region.

Plate 3 Taro breeding field plot, USP Samoa*

*Mary Taylor, Director CePaCT and the USP plant breeder, Tolo Iosefa and other PAPGREN workshop participants

It was through TaroGen that taro germplasm was introduced from outside the region. Cycle Five saw the introduction of TANSAO South East Asian lines from SPC. This broadened the genetic base to provide the prospect of developing new varieties with such qualities as greater disease resistance, good eating and drought tolerance. Unlike Cycle Four, the progeny from the Cycle Five crosses showed a huge diversity in types. This variety is described in the following SPC Land Resources News Letter.

> Taro plants that were dwarf and TLB-susceptible to plants that were large (over 2 m) aggressive and highly tolerant to TLB, from dark to sickly plants to handsomely coloured plants, from single to multiple shoots – some up to 50 shoots and thus threatening invasiveness, producing no corms to plants producing consumer preferred corms (April 2009).

With the selection of promising lines from such genetic diversity, it was possible to breed back taro Niue to see if the variety's palatability could be achieved without sacrificing disease susceptibility. Several Cycle Five(which have taro Niue genes from Cycle Three breeding) varieties were selected for the 6th breeding generation. These clones were pollinated, using pollen from the Niue variety to generate Niue first backcross generation (Cycle Six or sixth generation of breeding). Some of these Cycle Six lines were selected for the making of Cycle Seven and the continuation of backcrosses. From Cycles Six and Seven, five varieties have been selected. The most favoured of these varieties are *Talo Mumu* and *Polovoli Samasama*. USP taro breeder Iosefa Tolo summarized what had been achieved.

> We crossed our preferred Samoan varieties with varieties from Indonesia and Malaysia that had leaf blight resistance. In that way, we could keep the traits of our familiar and locally adapted varieties, and integrate disease resistance. It took time and a lot of work, but ultimately it was successful (ACIAR 2011).

Beginning in 2009, some thirteen years after the breeding programme began, new varieties began to be widely promoted to farmers for local sales and exports, although the distribution of these varieties is still constrained by the availability of planting material.

The problem of TLB has been essentially solved and a satisfactory degree of local market consumer acceptability has been achieved. However, more work would seem to now be required on overseas market consumer acceptability and breeding for the preferences of this market, if exports are to be restored to pre-blight levels. Emphasis is also now shifting to drought tolerance as a climate change strategy.

The participatory nature of Samoa's taro breeding programme

From the outset, there was a high degree of farmer participation in the taro germplasm development programme in Samoa. This is illustrated in farmer rankings for the evaluation of the first wave of exotic acquisitions that were presented to farmers for their consideration (table 1).

Table 1 Summary of farmers ranking of earlier exotic taro cultivars [1,]

Cultivar	Vigor	Yield	TLB resistance	Sucker production	Palatability
PSB-G2 (taro Fili)	3.1	2.4	2.0	3.4	4.0
Pastora	3.8	3.3	2.9	3.2	1.6
Pwetepwet	3.4	2.9	2.7	3.8	2.2
Toantal	3.3	2.3	1.7	2.7	3.5
Palau 3	3.3	3.0	2.6	3.1	2.9
Palau 4	3.1	2.1	2.6	3.9	3.1
Palau 7	3.5	3.0	2.8	2.8	2.4
Palau 10	3.9	3.8	3.5	3.2	3.2
Palau 20	3.7	3.5	2.6	2.9	3.6
Niue (post – 1993)[1]	1.9	2.0	1.1	1.9	1.9
Niue (pre – 1993)	3.9	3.9	-	3.1	4.0

* Source: Hunter *et.al.* 2007. Rankings for all criteria are based on 1 = unacceptable; 2 = okay, but not good; 3 = good; 4 = outstanding.
[1]Farmers were asked to rank *Niue*, the preferred cultivar of Samoans, for the criteria highlighted before and after the arrival of TLB in the country.

Grower participation in the breeding programme was formalized with the Taro Improvement Project (TIP) that commenced in 1999. Under TIP, farmer focus groups (Taro breeder clubs) were established to provide options for managing TLB. It is based at USP and involves Ministry of Agriculture Research and Extension staff. Membership was open to all farmers who agreed to compare taro cultivars, using a farmer participatory plant breeding (PPB) approach and take part in focused group discussions on their performance (see Hunter *et.al.,* 2007) (plate 4).

Plate 4 Taro growers attend a TIP meeting at USP Alafia in May 2011

Plate 5 A TIP farmer's field trial

Efforts were made from the outset to ensure good geographical coverage of the island when selecting farmers and this remains the case. Men have dominated these groups, which is a reflection of gender balance in taro cultivation in Samoa. Over TIP's thirteen years of existence, more than 100 farmers have been involved and several thousand taro plants have been evaluated on their farms. The first farmer-managed trials were planted in July 1999 and involved Cycle Two varieties. The TIP, as a classic plant breeding approach, took more than another decade to achieve substantive results. Yet, throughout that time, the interest of the participating farmers was maintained. This is reflected in fact that the TIP farmers continue to be willing to meet their own travel expenses to meetings at USP Alafua Campus. A notable feature of TIP farmers is their relative youth. Field meetings with TIP farmers revealed a high level of interest and technical knowledge about the varieties that they were planting and their ability to distinguish varieties, despite an apparent similar outward appearance. These participating farmers were very much farm-level research assistants.

The methodology used in this participatory plant breeding approach is summarized by Hunter *et.al,* 2007 and described briefly below.

<u>Participatory Rural Appraisals (PRAs)</u>
Crop-focused PRAs are conducted with farmer groups to learn more about taro production problems, perceptions of taro cultivars and criteria important in the selection of a cultivar. PRA techniques

Plate 6 A TIP farmer collecting has cycle 6 planting material after meeting at USP

included focused group discussions (FGDs), farm visits, farmer interviews and ranking exercises. The PRAs were conducted by a facilitator based at USP.

Farmer-managed trials of the planned programme of evaluations are described at TIP meetings (Plate 5). Researchers provided farmers with taro cultivars with a range of characteristics and TLB resistance. It was up to each farmer to identify those cultivars that they considered to be most suitable for their environment. Farmers visited demonstration sites at the USP to observe the cultivars close to harvest. The data accumulated was discussed with farmers. The evaluation process was described and appropriate on-farm trial layouts discussed. Farmers were given up to eight cultivars with 10 planting suckers per cultivar (Plate 6). Trial design was a simple non-replicated layout, using single rows of each cultivar with farmer traditional spacing. The importance of labelling, plot maintenance and a trial layout plan were stressed with no use of fungicides. On-going management of trial plots is based on normal farmer practice and the responsibility of farmers.

Plate 7 Grower tasting at a TIP meeting

Evaluation of the trials Monthly TIP meetings held at USP have been the main forums for FGDs and other PRA exercises. Some farmer-to-farmer visits are organized to allow participating farmers to observe other trials for comparison. Simple data sheets for vigour and disease score were explained and distributed to each farmer. The importance of data collection was highlighted as well as the requirement to feedback information to monthly FGDs as a learning experience for the group.

In FGDs criteria, such as vigour, yield, TLB resistance, suckering ability and palatability were scored, using a ranking system based on one to four(unacceptable to outstanding). Farmers were also requested to notify researchers as cultivars matured so accurate yield data could be collected. All corms and planting material remained the property of farmers.

The consolidated farmer evaluations for the pre-selected Cycle Two cultivars are presented in Table 1. All household members are encouraged to prepare and cook taro corms at home and provide information on quality. Farmers bring corms of cultivars to monthly FGDs for assessment of quality.

Grower and consumer response to the new taro varieties

Virtually all of the substantial volume of taro grown in Samoa today is a product of the taro breeding programme. This is the conclusive evidence of the strong grower and consumer acceptance of the introduced varieties. Discussions with TIP growers and staff suggest that the high demand for the new taro germplasm is not perceived by the growers as an adaptation response to climate change. The demand of village farmers for this material is driven directly by the loss of their most important food staple and income source. However, it has been found that Samoan farmers are increasingly associating diseases such as TLB with climate change[15].

The new taro varieties are now well accepted by Samoan consumers living in Samoa – despite the fact that taro consumption still remains well below the pre-TLB level. The involvement of TIP growers in selection taste panels has contributed significantly to local consumer acceptability. Yet consumer acceptability of the new varieties in New Zealand has lagged behind local consumer acceptability. There was an assumption that if these new varieties were acceptable to Samoa at home, they would be acceptable to Samoans living abroad. Accordingly, taste testing panels on which selection was based were made up entirely of local Samoans (TIP members and Ministry of Agriculture Staff – Plate 7). This assumption proved not to be entirely valid. Samoans living in New Zealand still had access to taro Niue source from Fiji and did not have the need to adjust to the new varieties[16]. This problem was compounded by the range of varieties being exported with variable taste characteristics. Often, these varieties are not readily distinguishable by physical appearance. The need to take into account the taste preferences of New Zealand-based consumers in the breeding programme is now recognised.

A recently approved ACIAR Pacific Agribusiness Research and Development Initiative (PARDI) Project aims specifically at identifying the taste and preferences of New Zealand-based taro consumers and incorporating these into the taro breeding programme. The taro project will focus on the supply chain of targeting constraints identified as preventing the effective supply of the market. The project aims to support the sustainable growth of Samoa's taro export market by developing a viable system for providing high quality planting material of an appropriate diversity of market-preferred varieties, supported by relevant information, to all supply chain actors. The specific objectives are to:

- Screen available varieties of taro for defined market opportunities, such as fresh exports, higher- value or more durable products (chips and other snack foods), partial processing (especially peeling and freezing or drying) and market acceptability;
- Improve methods for multiplying/delivering disease- and pest-free planting material;
- Establish viable private-sector nurseries for commercial multiplication and dissemination of new, high quality, TLB-resistant and market-preferred varieties; and
- Strengthen the supply and flow of crop- and market-related information along the taro supply chain.

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[15] This was a finding of Laisene Tuioti Mariner in her parallel Samoa study "An analysis of adaptive capacity in relation to several SPC agro-biodiversity/food security projects". This study is funded by DCCEE under PASAP.

[16] USP Professor, David Hunter, provided personal insight into the adjustment of tastes and preferences over time. "Over time we in Samoa came to accept that the best of the new varieties were just as good as 'Talo Niue'. However, when I recently visited Taveuni in Fiji for a workshop and I was able to eat 'Tausala ni Samoa' I realized what 'Talo Niue' used to taste like and what we have been missing!"

The expected outputs will be: identification of additional disease-resistant varieties suitable for specified markets (fresh local or export; processing and value-adding); improved techniques for eliminating viruses and excluding other pests and diseases and improved multiplication techniques for both the laboratory and field use; a pilot-level nursery system, capable of sustainable delivery of high-quality planting material; improved flow of information, regarding varieties and market opportunities for farmers and other supply chain actors. All of these outputs will contribute to the main project outcome which is the development of an effective supply chain for taro.

Quantifying the cost of TLB for Samoa

The cost of the adaptation (the spraying programme)

The initial TLB response effort focused on the containment of the disease via the use of fungicides. The Samoan government spent some WST 600,000 on chemicals and their application. To this has to be added expenditure of farmers on the purchase of chemicals. There was additional public expenditure on extensive publicity and quarantine campaign. An indicative estimate of these total costs is WST 1million. Unfortunately, these measures ultimately proved ineffective.

The loss of food self sufficiency: measured in terms of the value increased imports of wheat and rice

The loss of the main food staple had a major adverse impact on Samoa's food security. An analysis of Samoa's FAO Food Balance Sheets shows that during the late 1980s, taro contributed around 430 kcal/person/day of food energy (Figure 11). In 1994 and 1995, the two years following the arrival of the blight, taro contributed an estimated 70 kcal/person/day of food energy (Figure 11). The deficit of around 360 kcal/person/day had to be obtained from other sources of food energy. Over time, there has been increased consumption of other domestic staples (banana, breadfruit and other root crops) and from 2001 onwards, there has been some recovery in taro consumption. However, most of the deficit was filled with a large increase in wheat and rice imports. During the late 1980s, imported wheat and rice contributed around 360 kcal/person/day of food energy (Figure 11). This was provided by an average 45kgs of imported grain per person per year (Figure 6). In 1994 and 1995, these imported grains contributed an estimated 590 kcal/person/day of food energy (Figure 11). This energy was provided by an average 78kgs of imported grain per person per year – or total grain imports of 13,000 tonnes (figure 9). Thus, in the few years immediately following the arrival of TLB in Samoa, additional grain imports of around 30 kg per person can be attributed to TLB. This represented a total annual increase in imported grain of around 5,000tonnes (a 38 per cent increase over the level of the late 1980s). The landed value of this increase in imported grain provides an economic measure of the loss of food self-sufficiency due to TLB. The estimate of the additional grain imports resulting from TLB are fixed at 30kg/head/year until 2000. From then on, this amount is allowed to fall at the rate of five per cent per year to reflect the increase in consumption of other local starches and the gains in local taro production, resulting from the taro breeding programme. On this basis, the annual economic losses are calculated in table 2. Over the 17 year period of 1994 through 2010, the total estimated economic cost resulting from reduced food self sufficiency due to TLB is WST 60 million.

Table 2 The estimated economic cost of loss of food self sufficiency due to TLB

	est. additional per capita grain imports due to TLB (kg)	population ('000)	total est. additionalgrain imports due to TLB (tonnes)	average landed value per tonne (USD)	average landed value per tonne (WST)	estimated economic of the loss of food self sufficiency(WST)
1994	30	167	5,010	268.65	658	3,297,529
1995	30	168	5,040	278.83	705	3,555,388
1996	30	170	5,100	231.81	563	2,872,857
1997	30	172	5,160	193.24	535	2,762,078
1998	30	174	5,220	169.54	510	2,663,880
1999	29.3	175	5,119	182.59	551	2,822,577
2000	28.5	177	5,048	151.71	507	2,557,707
2001	27.8	178	4,949	150.86	536	2,650,679
2002	27.1	178	4,826	188.58	607	2,930,244
2003	26.4	179	4,731	228.14	634	3,000,818
2004	25.8	179	4,613	303.87	811	3,742,880
2005	25.1	179	4,498	189.55	523	2,353,055
2006	24.5	179	4,385	360.89	971	4,257,379
2007	23.9	179	4,276	323.97	829	3,546,223
2008	23.3	180	4,192	563.93	1,641	6,879,544
2009	22.7	180	4,087			5,000,000
2010	22.1	181	4,007			5,000,000
Total						**59,892,837**

The loss of export earnings

Over the five years prior to the arrival of TLB Samoa exported an average of 5,500 tonnes annually for an average fob value of WST 5.9 million. In Table 3, forecasts are made of what Samoa's taro exports would have been without TLB. These forecasts are based on a 1.5 per cent annual growth rate in the volume of exports. The small amount of taro that has been exported post-TLB has mainly been to American Samoa. The fob price for taro sold to Pago Pago is about double that received for taro sold to New Zealand. However, the American Samoa market is quite limited. Thus, the forecast price without TLB is assumed to be only 50 per cent of the price of taro actually exported to American Samoa. The forecast exports without TLB are compared with Samoa actual exports over the same period. The difference between the "with" and "without" scenarios provides the estimated loss in export earnings resulting for TLB. These losses are graphed in Figure 13. The total volume of Samoan exports foregone over the period 1994 through 2010 is estimated at approximately 112, 000 tonnes, with an estimated fob value of WST 196 million (or an average annual loss of export income WST 12 million).

The total quantifiable economic cost of TLB to Samoa

Table 4 summarizes the cost estimates of the impact of TLB on Samoa over the period 1994 through 2010. The total estimated economic cost is almost WST 260 million, or an average annual economic cost of 16 WST million.

Table 3 Total estimated economic cost of TLB to Samoa

	Total estimated cost ('000 WST)	Average annual estimated cost ('000 WST)
Spraying and other adaptation measures	1,000	63
Loss of food security	60,000	3,750
Exports foregone	196,000	12,250
Total	**257,000**	**16,063**

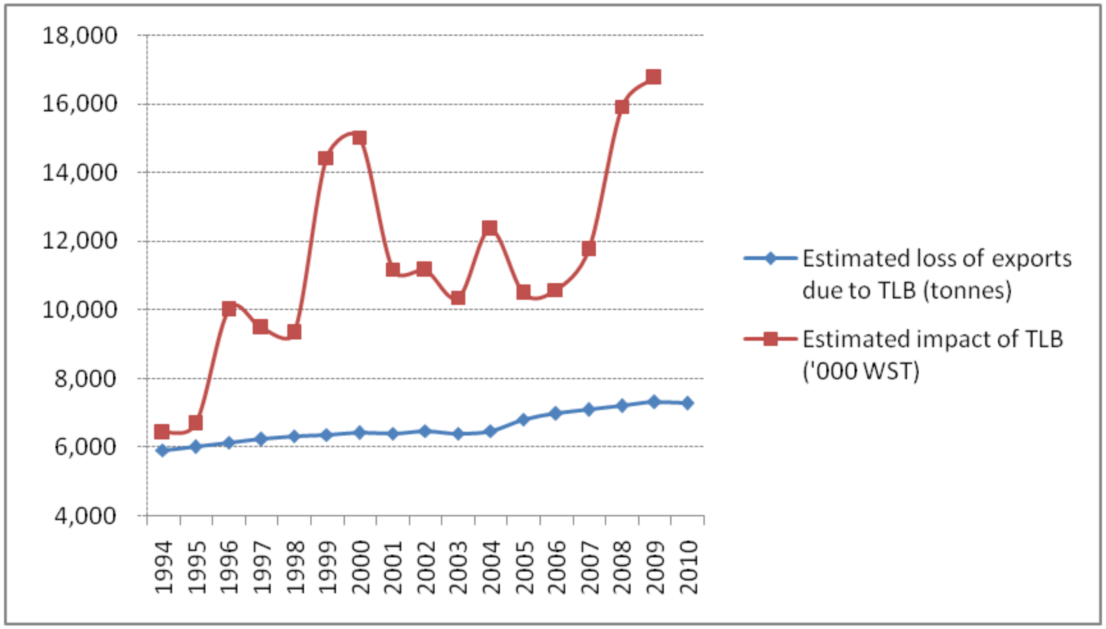
Non quantifiable costs

The impact on health and nutrition resulting from TLB as discussed above is substantial, although it is not readily quantifiable.

Table 4 Estimated impact of TLB on Samoa's export earnings

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Actual taro exports (tonnes)	3210	6060	72	72	30	32.4	38.1	90	132	246	279	446.7	480	263.7	190.8	183	189	186	333
Actual value (1,000 WST fob)	4,696	9,509	158	162	98	99	113	432	716	814	1,005	1,314	1,975	846	595	622	858	874	1,109
Estimated exports without TLB (tonnes)	3210	6060	6,000	6,090	6,181	6,274	6,368	6,464	6,561	6,659	6,759	6,860	6,963	7,068	7,174	7,281	7,391	7,501	7,614
Estimated value without TLB (1,000 WST)	4,696	9,509	6,583	6,851	10,096	9,585	9,444	15,513	17,793	11,017	12,173	10,090	14,325	11,337	11,185	12,374	16,775	17,624	12,678
Estimated impact of TLB (tonnes)	0	0	5,928	6,018	6,151	6,242	6,330	6,374	6,429	6,413	6,480	6,414	6,483	6,804	6,983	7,098	7,202	7,315	7,281
Estimated impact of TLB ('000 WST)	0	0	6,425	6,689	9,998	9,486	9,331	15,081	17,077	10,203	11,168	8,776	12,350	10,491	10,590	11,752	15,917	16,750	11,569

Figure 17 The estimated economic cost of Samoan taro exports foregone resulting from TLB



Quantifying the benefits and costs of the Samoan taro germplasm development programme

The benefits to date

Samoa today would be producing virtually no taro had there not been the public invest in the taro germplasm development programme.

Plate 8 Colocasia and alocasia being sold together the Fugalei market

The Fugalei Market Surveys indicate that around 500 tonnes of taro is now sold annually. The total consumption of all types (*Colocasia, Xanthosoma* and *Alocasia)* is now in the order of 18,000 tonnes. This estimate is derived from data provided by the FAO food balance sheets. It is not possible to disaggregate the between the types of taro. However, field and Fugalei market observation, together with discussions with TIP participants would suggest that around 50 per cent of this taro would be *Colocasia*. Subsistence taro is valued at the Fugalei market price – this being the measure of what consumers would pay for taro if it was purchased). Based on the average Fugalei price of WST 2.30/kg, the estimated value of 9,000 tonnes of *Colocasia* taro consumption consumed annually is almost WST 21 million. To this has to be added the value of taro that is exported. In 2010 the fob value of exported taro was WST 1.1 million.

The benefits from the germplasm development started to be realized from 1997 onwards. Estimated economic value of these benefits is presented in table 5. The value of these benefits, despite the lag in their realization, has far exceeded the cost of developing and distributing the germplasm.

Future expected benefits

The benefits from the germplasm development programme will continue to be realized into the future.

Domestic consumption

Domestic taro consumption still remains below half what it was prior to TLB. Thus continued growth in domestic taro consumption can be expected – albeit at a declining rate. Over the intervening 17 years there have been fundamental changes in Samoan food consumption patterns. The Samoan food balance sheets show that per capita rice and wheat consumption has doubled over the last 20 years. At current grain price levels it is unlikely that the consumption of imported grains will be significantly reversed with the increased availability of taro. However, higher and even more volatile world grain prices can be expected in the future (Christiaensen, 2011). It conservatively estimate that over the next decade the domestic consumption of taro will increase to around 10,000 tonnes – in line with a modest increase in per capita consumption and with population growth. The value of this taro, at current Fugalei market prices, would be around WST 25 million by 2020 (table 6).

Exports

Greater growth can be expected in the export of taro, than in domestic consumption, over the next decade. This will occur with greater acceptance of the new varieties by the Samoan community living in New Zealand and the further development of new varieties that meet the taste requirements of Samoans living overseas. In Table 6, a 10 per cent annual growth in volume of taro exports is projected. A fob price of WST 2.50/kg is assumed over this period[17]. The value of these exports by 2020 would be around WST 2 million.

Some offsetting benefit losses to other PICs

Offsetting the benefits to Samoa of increasing taro exports to New Zealand will be the loss of market share to Fiji. However, it should not be a zero sum game with respect to taro exports to from New Zealand from Samoa and Fiji. The taro market to New Zealand can be significantly expanded if prices can be lowered through enhanced efficiency and improved market access (McGregor *et.al*, 2010). More importantly the Samoan taro development programme has provided insurance for Fiji taro against the future eventuality of TLB. These future adverse impacts would be lessened further if Fiji now initiates its own taro germplasm development programme building on the Samoan experience.

Regional and international benefits

There are benefits beyond Samoa from the taro germplasm development programme. For those countries that do not yet have TLB, the programme has provided a degree of insurance against this future eventuality. It took Samoa nearly 5 years to effectively respond to TLB. This response period can now be substantially reduced thanks to the Samoan programme. Blight tolerant taro varieties could be imported from Samoa immediately after the incursion of TLB. However, ideally to minimize the impact these resistant/tolerant varieties should be in-country and distributed to farmers prior to the arrival of TLB. The experience of Vanuatu is that far better results are achieved in term of performance and acceptability if local germplasm is incorporated into the breeding programme. There has been regional capacity building through USP's participation in TaroGen. This has given the capacity to individual countries to initiate their own taro breeding programme. However, substantial technical support is required if individual country breeding programmes are going to be successful. This study demonstrates the substantial economic benefits that arise from this support. Thanks to the initial efforts of the TaroGen programme, sustained by SPC and USP, there is now greater regional awareness of the importance of creating genetic diversity in taro and root crops generally and the risks country's face with their current narrow gene pool.

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[17] Based on Fijian taro fob values

Table 5 The estimated economic benefits to Samoa from the taro germplasm development programme

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Estimated taro consumption (all types) (tonnes)	5,000	5,000	7,000	14,000	14,000	15,000	15,000	15,000	15,500	16,000	16,000	16,000	16,000	16,500	17,000	17,000	17,500
percent colocasia	0.05	0.04	0.04	0.15	0.15	0.15	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.50	0.50	0.50
Estimated colocasia consumption (tonnes)	250	200	280	2,100	2,100	2,250	2,250	3,000	3,875	4,800	5,600	6,400	7,200	8,250	8,500	8,500	8,750
estimated consumption resulting from the germplasm program (tonnes)	-	-	-	1,900	1,900	2,050	2,050	2,800	3,675	4,600	5,400	6,200	7,000	8,050	8,300	8,300	8,550
Fugalei market price ('000 WST/tonne				6.24	6.27	5.19	3.04	2.16	2.13	1.73	3.06	2.32	2.16	2.48	3.14	3.24	2.30
Imputed value of taro consumption resulting from the germplasm program ('000 WST)	-	-	-	11,856	11,913	10,644	6,224	6,037	7,842	7,944	16,543	14,356	15,092	19,998	26,066	26,873	19,688
Value of taro exports resuling from the germplasam program ('000 WST)	-	-	-	-	-	432	716	814	1,005	1,314	1,975	846	595	622	858	874	1,109
Total estimated benefits from the germplasm project ('000 WST)	**-**	**-**	**-**	**11,856**	**11,913**	**11,076**	**6,940**	**6,851**	**8,847**	**9,258**	**18,518**	**15,202**	**15,687**	**20,620**	**26,924**	**27,747**	**20,797**

Table 6 Estimated future benefits accruing to Samoa from the taro germplasm development programme

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
tonnes consumed	8,969	9,193	9,423	9,658	9,900	10,147	10,401	10,661	10,928	11,201
value ('000 WST)	20,628	21,144	21,672	22,214	22,770	23,339	23,922	24,520	25,133	25,762
tonnes exported	350	385	424	466	512	564	620	682	750	825
value ('000 WST)	875	963	1,059	1,165	1,281	1,409	1,550	1,705	1,876	2,063
Total value of taro production ('000 WST)	21,503	22,106	22,731	23,379	24,051	24,748	25,472	26,225	27,009	27,825

Total domestic and export benefits

On the basis of the above, the total annual value of taro produced by 2020 would be around WST 28 million.

The cost of the taro germplasm development programme

Public investment costs

It is estimated that over the period 1994 through 2010, the equivalent of WST 18 million (AUD 8 million) has been spent on taro germplasm development and distribution. This figure takes into account the costs of the following partners[18]:

- **AusAID funding of TaroGen**
- **ACIAR funding** of the UQ (DNA fingerprinting and virus testing) the QU (developing of methods for the diagnosis and detection of viruses)
- **New Zealand Ministry of Foreign Affairs and Trade** funding of HortResearch to develop methods to assess TLB resistance
- **A share of the running of the SPC gene bank at CePaCT**

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[18]The specific contributions of the various partners are:

- **AusAID funding of TaroGen** - AUD 2.3 million (spent over five years, commencing in 1998)
- **ACIAR funding** of the University of Queensland (DNA fingerprinting and virus testing) the Queensland University of Technology (developing of methods for the diagnosis and detection of viruses – AUD 1,576,300 (spent over two years, commencing in 2002)
- **New Zealand Ministry of Foreign Affairs and Trade** funding of HortResearch to develop methods to assess TLB resistance – NZD 234,000 (spent over three years, commencing in 1999). 50 per cent of this cost is attributed to the Samoan taro germplasm develop programme.
- **Running the SPC genebank at CePaCT** – USD 180,000 per annum from 1999. Taro makes up about 70 per cent of that collection, with around 35 per cent of the accessions available for distribution because they have been tested for viruses. CePaCT Manager, Dr Mary Taylor, suggests that one-third of the total costs for CePaCT maintaining taro should be attributed to Samoan Taro Improvement Project (TIP). This is despite the fact probably no more than 20 accessions (2.5 per cent of the total) have been utilized in Samoa.
- **SPC funding after TaroGen –** The full salary of the plant breeder for four years (WST 48,000/year) and then WST42,000/year for three years. Also met operational costs for seven years (FJD 15,000/year)
- **USP funding prior to TaroGen** – WST 200,000 (spent over four years, commencing in 1994)
- **USP funding after TaroGen** –WST 520,000(spent over seven years, commencing in 2003)
- **Samoa Ministry of Agriculture** –WST 5 million (spent over 17 years).Based on an estimate of approximately 30 per cent of the Ministry of Agriculture's budget being spent on testing and distribution taro germplasm

- **SPC funding after TaroGen**
- **USP funding prior to TaroGen**
- **USP funding after TaroGen**
- **Samoa Ministry of Agriculture** cost of testing and distribution of taro germplasm
- **Samoa Ministry of Agriculture** WST 5 million (spent over 17 years). Based on an estimate of approximately 30 per cent of the Ministry of Agriculture's budget being spent on testing and distribution taro germplasm

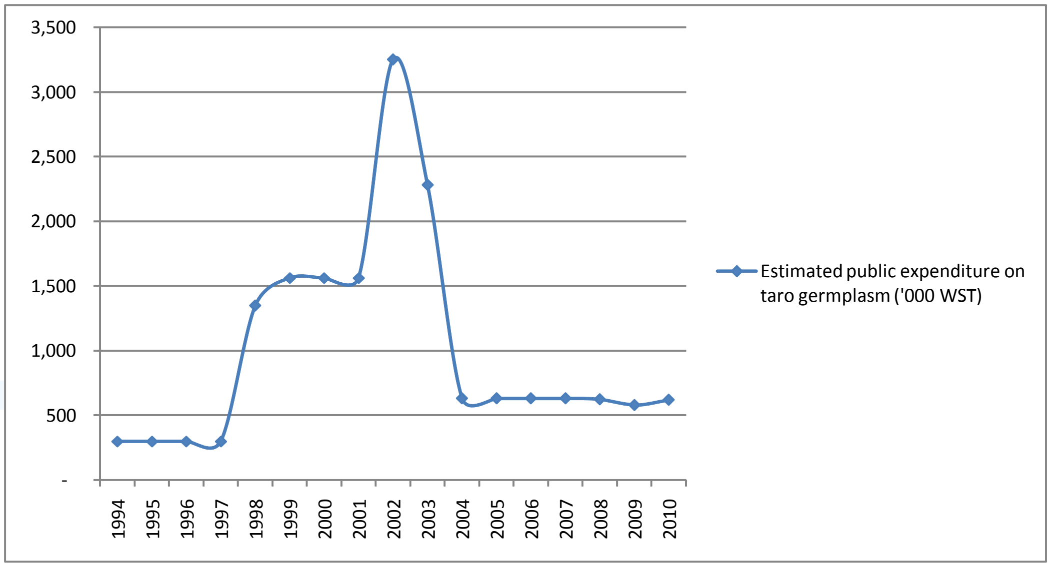
It is estimated that over the period 1994 through 2010 the equivalent of WST 18 million have been spent on taro germplasm development and distribution. The distribution of this expenditure through time is presented in Table 7.

Cost to farmers

There are no additional private costs incurred by farmers as a result of the germplasm development project. There are no additional purchased inputs required by farmers, such as fungicides, to grow these new varieties. There are also no significant additions in labour input requirements.

Table 7 The expenditure on Samoan taro germplasm development and distribution (WST ‘000)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
AusAID funding of TaroGen					1,020	1,020	1,020	1,020	1,020									**5,100**
ACIAR DNA/virus testing									1,760	1,760								**3,520**
NZ Aid						70	70	70										**210**
SPC genebank						143	143	143	143	143	143	143	143	143	143	143	143	**1,716**
SPC					20	20	20	20	20	20	78	78	78	78	72	28	28	**560**
USP	50	50	50	50	10	10	10	10	10	60	60	60	60	60	60	60	100	**770**
Samoa Dept Agricultur	250	250	250	250	300	300	300	300	300	300	350	350	350	350	350	350	350	**5,250**
	300	300	300	300	1,350	1,563	1,563	1,563	3,253	2,283	631	631	631	631	625	581	621	**17,126**



Comparing programme benefits with programme costs

Comparing realized benefits with actual costs to date

It is some 17 years since the Samoan taro germplasm programme commenced in its various components. Thus, there is a long stream of actual estimated benefits to compare with actual financial costs. Over the period 1994 through 2011 the quantifiable benefits have been more than 10 times that of the cost of programme (Table 8). The net present values (NPVs) are calculated for benefits and cost for a range of discount rates. A low rate of discount would be justified for evaluating such a development programme, given that wide community benefits that will be enjoyed by future generations of Samoa. However, the benefit cost ratios obtained are not to be particularly sensitive to the discount rate applied (table 8). For a discount rate of two per cent (which could be regarded as an appropriate social rate of discount for a long, broadly-based development project) the benefit cost ratio is 10.7. When the discount rate is increased to 15 per cent (a discount rate more appropriate for a private investment project with a relatively short time horizon) there is actually a small increase in the benefit cost ratio. This apparent anomaly can be explained by the unusual flow of programme benefits and costs through time from the two successive germplasm programme parts. The first part of the programme was the early exotic introductions from Micronesia and the Philippines. These were evaluated and then distributed to farmers via programmes supported by FAO and JICA. This was followed by the longer term taro breeding part of the programme. The cost of acquiring and distributing these early acquisitions from Micronesia and the Philippines was quite low. A few of these early varieties, such as taro *fili*, realized relatively large benefits within a short timeframe. These early benefits soon reached a ceiling and the focus turned to a long-term breeding programme. The major expenditure did not begin until the breeding programme proper began (with TaroGen in 1998 and the ACIAR component in 2002). There was then a lag of several years before the benefits from the taro breeding proper began to be realized. The conclusion that can be drawn from this analysis is that the Samoan taro germplasm development programme has been a highly worthwhile public investment. This conclusion is not dependent on the discount rate chosen.

Extrapolating benefits and cost into the future

The benefits from the Samoan germplasm development programme will continue to be realized well into future. Estimates of these benefits through until 2020 are made in Table 6. There will be ongoing costs associated with the realization of these benefits as the breeding and extension programme continues to work on gaining greater consumer acceptability in export markets and begins to breed for greater drought resistance. Additional investment will be required to achieve these objectives. An annual expenditure of WST800,000 (in 2011 prices) is provided for in the projections. Taking into account these future benefits and costs, there is a substantial increase in the B/C ratio (Table 9). These ranged from 16.4 for a zero discount rate of interest to 15.1 for a 15 per cent discount rate. The expected inverse relationship between the B/C ratio and the discount rate is restored as future benefits and costs are taken into account and offset early against low cost benefits of the initial exotic introductions. This result further confirms the exceptionally high economic return from the public investment in the taro germplasm programme.

Table 8 Comparing estimated realised benefits with costs from the Samoan taro germplasm development programme

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Program benefits('000 WST)						11,856	11,913	11,076	6,940	6,851	8,847	9,258	18,518	15,202	15,687
Program costs ('000 WST)	300	300	300	300	1350	1563	1563	1563	3253	2283	631	631	631	631	625
Benfits - Costs	(300)	(300)	(300)	(300)	(1,350)	10,293	10,350	9,513	3,687	4,568	8,216	8,627	17,887	14,571	15,062

	r(i) = 0	r(i)= 2%	r(i) = 5%	r(i)=10%	r(i)=15%
NPV Benefits	**185,195**	**157,873**	**126,338**	**90,852**	**68,491**
NPV Costs	**17,626**	**14,695**	**11,374**	**7,722**	**5,473**
B/C	**10.5**	**10.7**	**11.1**	**11.8**	**12.5**

Table 9 The estimated benefit cost ratios of the taro germplasm programme when future projected benefits and costs are taken into account

	r(i) = 0	r(i)= 2%	r(i) = 5%	r(i)=10%	r(i)=15%
NPV Benefits	**408,195**	**313,659**	**218,923**	**131,487**	**87,236**
NPV Costs	**24,826**	**19,267**	**13,737**	**8,551**	**5,782**
B/C	**16.4**	**16.3**	**15.9**	**15.4**	**15.1**

Conclusions and recommendations

The Samoan case study demonstrates that a taro leaf blight epidemic represents a major disaster with large economic and social consequences.

A rise in minimum night time temperature increases the likelihood of the TLB spreading to locations that are currently free of the disease. This temperature increase will increase the severity of the disease when it does occur. Areas that are now free of TLB, such as Fiji, Tonga, Vanuatu, the Cook Islands and higher elevation areas of PNG, are all seen to be at high risk.

All of Oceania's traditional crops are vulnerable to the impact of climate change due to their narrow genetic base. There is need to broaden this genetic base of these crops to avert future epidemics and disasters. Samoa was able to successfully overcome the disaster of taro leaf blight through a concerted and systematic long-term breeding programme that introduced and selected taro germplasm resistant/tolerant to TLB.

Due the obvious severe consequences of the TLB disaster, it was possible to eventually focus the attention and of national government agencies (primarily the Samoan Ministry of Agriculture), regional bodies (SPC and USP), aid donors (AusAID, NZ AID and ACIAR). Proactive action is required for countries and for other traditional crops to avert similar disasters occurring. This is the basis of the Vanuatu germplasm distribution programme which is analyzed in a second case study.

The Samoan germplasm development programme has been highly successful when measured in conventional benefit cost analysis terms. The imputed value of the taro produced over the last 17 years as a result of the programme is more than ten times the expenditure of public funds on the programme. To this has to be added less quantifiable benefits such as improved health and nutrition. The difference between the benefits and costs of the programme will increase into the future.

It is projected that by 2020 the benefits that have risen from the programme will be more than 15 times the cost of the programme. It would be difficult to find a public investment/donor funded project in the Pacific islands, particularly in the agricultural sector that anywhere near approaches that rate of return.

The success of the Samoan taro breeding programme can be attributed to:

- A major crisis that made it possible to focus the minds of government decision makers and donor agencies. It was thus possible to eventually secure the necessary coordinated and sustained response of the funding and implementing agencies. Eliciting an ex-ante response of equivalent scale is a much more difficult task – although this is what is now required for other countries and for other traditional crops.
- The high calibre of the key people involved in the identification of project and its subsequent implementation. In particular, the USP taro breeder has from the outset been critical to the success of the programme.

- The direct involvement of farmers in the taro breeding programme.
- The existence of a regional germplasm banks at SPC and USP. Importantly, the success of the taro breeding programme was made possible because of the access to diversity through the Pacific region's genebank, in particular, the south-east Asian taro from the TANSAO project which provided the much needed diversity to progress the breeding programme to the stage it is at today. For Samoa to have imported this material directly would have been very difficult, especially taking into account the need for virus testing.

The Samoan programme took several years to get started – which meant there were substantial costs in terms of lost benefits. An important lesson learnt for other countries is the need to be able to respond quickly to arrival of TLB. A proactive response is required, with the germplasm in-country and, ideally, in the hands of the farmers prior to the arrival of the disease. The Vanuatu programme is an example of how this can be done.

4. Broadening the genetic base of root crops in Vanuatu: a proactive climate change adaptation strategy

The Vanuatu approach, in contrast to that described for Samoa, relies on evaluating local diversity, incorporating some exotic diversity, and then distributing large volumes of planting material for farmers to select from, and then to conserve. It very much relies on the interest and enthusiasm of the farmer to want new diversity and importantly not to abandon any old, traditional varieties for this new diversity; this could be unique to Vanuatu farmers. Unlike the more targeted approach as illustrated by Samoa, the diversity in the farmers' field is significantly enhanced, which could have huge benefits in managing climatic variations. In applying this approach to other countries, it has to be remembered however, that the effectiveness of this diversity enhancement does rely to some extent on the farming practice of shifting gardens which allows for cross-pollination to occur.

Case study background

The food security of western Melanesia and the threat of climate change

At a national level, the countries of western Melanesia have a much lower dependency on imported foods and enjoy a higher level of food security when compared with the countries of Polynesia and Micronesia (McGregor *et al,* 2009). In surveys undertaken in PNG, for example, Bourke and Harwood (2009) found that 83 per cent of food energy consumed in 2006 was from locally grown foods. For the Solomon Islands, it was calculated that imported grains contributed 21 per cent of the food energy consumed at the national level in 2004 (Bourke *et al,* 2006). For Vanuatu, a detailed study of food production on Malo Island in 1997 also found that 21 per cent of villagers' food energy needs came from imported food and most of the rest from locally grown food (Allen, 2001). Malo can be considered a 'typical island' in Vanuatu, being neither particularly remote nor influenced by urbanisation. Among the Melanesian countries, Fiji imports a much higher percentage of calories (58 per cent) and protein (60 per cent) needs (McGregor *et al,* 2009).

The traditional Melanesian food garden provides the majority of the population with a high degree of food security even in the face of natural disasters such as cyclones. However, the high level of food security is at considerable risk due to the narrow genetic base of the traditional crops upon which this security is based. Into the future, Pacific island farmers will face extremes of climate – be this in the form of excessive and prolonged rainfall and flooding, extended droughts, severe cyclones and exceptional tides. Staple crops with a narrow genetic base are particularly vulnerable to these extremes.

FAO (2008) makes specific longer term climate change forecasts for Vanuatu:

> On the basis of climate scenario modelling[19] and historical records available, it has been predicted that climate change over the next century will lead to warmer and drier conditions in much of Vanuatu with the size of the change increasing away from the equator (National Advisory Committee on Climate Change NACCC, 2007). However, the possibility of increased rainfall should not be dismissed. These effects will be accentuated by more frequent and severe cyclone events. Heavy rainfall is a normal component of cyclonic storms so a greater proportion of rain will be associated with the passage of storms. Indications are that there will be more frequent El Nino type conditions which are usually associated with prolonged dry seasons (p. 33).

Vanuatu's traditional cropping systems and disaster coping mechanisms

The Vanuatu Land Use Planning Project's 'Profile of Self Sufficiency Food Crops' describes three broad types of smallholder farming systems prevailing in Vanuatu today (2000). These are:

- multi-cropping self-sufficiency food gardens, which are either yam or taro based;
- semi permanent continuous irrigated cultivation of taro; and
- smallholder tree crop production usually based on coconuts, with the household maintaining a separate multi-cropping food garden.

Within these broad categories, a wide range of cropping systems can be delineated.

[19] The models referred are the SCENGEN scenario generator with two Global Circulation Models: HADCM2 and CSIRO9M2.

Plate 11 Yam laplap Brenwe Malakula

The self-sufficiency multi-cropping food garden

This system is based on the annual clearing of forest or fallow bush to establish several multi-crop family food gardens. Plots are rain-fed and intensively cultivated for one to three years. Some residual longer-term crops such as bananas and taro remain in the garden for several more years. These plots are then returned to bush fallow before being used again for cropping. Each cropping system of beliefs, customs, rites and cultural traditions linked to either taro or yam (Bonnemaison, 1986). In drier areas, yams (*Dioscorea spp*.) are the pivotal crop in the system, while in wetter locations, taro (*Colocasia esculenta)* is the pivotal crop.

Plate 9 Taro based cropping system Middle Bush, Tanna

Plate 10 Yam based cropping system Avunamalai, Malo island

Banana, sweet potato and cassava have become increasingly important in most locations in Vanuatu. Island cabbage (*Abelmoschus manihot*) is invariably part of most food gardens. Corn is probably the next most important crop, with a range of other vegetables often found scattered through food gardens. Food derived from these multi cropping garden systems, if supplemented by outside sources of protein, readily satisfies the nutritional requirements of the household. Work of the South Pacific Commission, dating back to the 1950s found 'that a mixed diet of yams, taro, or sweet potato with green leaves would supply a balance of amino acids necessary for an adequate diet' (Peters, 1959). As outlined in Table 10, a standard 300 gm *laplap* (Plate 9) portion meets over 30 per cent of daily energy requirements, a significant portion of vitamin and mineral requirements, but low proportion of protein requirements.

Table 10 The nutritional value of standard portion (300 gm) LAPLAP (island cabbage, Xanthosoma taro, coconut cream)*

Ingredients	Weight (gm)	Energy (kJ)	Protein (gm)	Dietary fibre	Potassium (gm)	Calcium (mg)	Iron (mg)	Tot Vit A equiv (µg)	Vit C (mg)	Vit E (mg)
Taro (raw gated - skin removed)	45	242	7	1.1	224	21	6	2.3	3.2	1.4
Island cabbage leaves (raw - stalk removed)	15	34	0.5	0.2	56	65	0.6	101	16	
Coconut cream	40	424	1.3			6.4	0.6			
Total		**700**	**2.5**	**1.3**	**280**	**92.4**	**1.8**	**103.3**	**19.2**	**1.4**
Recommended dietary intake		3000**	50***		1000	850	8.5	750	35	8.5
% of recommended intake		**23**	**5**		**28**	**11**	**21**	**14**	**55**	**17**

*Source: Based on information provided by Mrs. Votausi Mackenzie – Reur, the proprietor of the Lapita Café. This was based on a laplap to serve 10 people. This laplap had the following ingredients: raw grated Fiji taro – skin removed (4.5 kg); raw island cabbage – stalks removed (1.5 kg); 4 large raw dried coconuts extracted medium coconut cream (400g or 500 ml); raw onion 200g; and salt (1 metric teaspoon). The same laplap could be made with any other staple (manioc, yam, banana). Sometimes the island cabbage is omitted and only coconut cream is used. Sometimes chicken, meat of seafood replaces the island cabbage.

Irrigated cultivation of taro

This system, known colloquially as water (wota) taro, involves the intensive and continuous cultivation of irrigated taro with a separate, multi-crop, annual food garden. This cropping system is restricted to those areas that had permanent running streams.

Small farmer tree cropping

This system involves a household growing a cash tree crop —usually coconuts, which might be under-grazed with cattle or inter-cropped with cocoa. Around 70 per cent of households' produce their own coconuts; most of these make copra at least on an intermittent basis (1993 Agricultural Census). Coconuts also provide a major source of subsistence. A household growing coconuts, will invariably maintain a separate traditional multi-crop food garden. The food garden will usually be located some distance from the village and beyond the coconut/cocoa plantation. The proportion of cash cropping to food gardening depends on the land and labour available, altitude and the household's adherence to traditional systems. The 2009 Agricultural Census indicates that the average household has approximately two ha of cash crops. According to the Census, each household will have an estimated 0.5 ha of productive food garden (in their first, second or third year) and more than three times that area will be fallow or contain residual crops such as kava and bananas.

These agricultural systems have allowed food supply to keep pace with Vanuatu's high population growth rate (2.3 per cent at 2009 Population Census), even on the most densely populated islands. Bourke 1999 attributes this achievement to the following factors:

- **The adoption of new, more productive staple crops**. Aelan taro (*C. esculenta*) and soft yam (*D. alata*) were traditionally the most important food crops, supplemented by strong yam (*D. nummularia*), breadfruit, bananas, and other minor crops. However, over the past 50-60 years, other new crops have become increasingly important. The most prominent of these has been Fiji taro (*Xanthosoma* spp.) and cassava. Cassava (*Manihot esculenta*) is robust, does not require much care and can grow on poor soils. Fiji taro has greater drought tolerance and is less susceptible to cyclones. Other new crops that have gained importance are sweet potato and Wailu yam (*D. rotundata*). Village growers appreciate sweet potato (*Ipomoea batatas)* because of its short production period and resistance to cyclones. All the new staples have been introduced from other parts of the world, such as South and Central America and West Africa. The introduced staples are higher yielding and require less management to maintain stocks of planting material. As a result, they have rapidly been integrated into ni-Vanuatu gardens and cultivated to supplement taros and yams.

- **The adoption of more productive cultivars of existing foods.** There has been much movement of germplasm into and around Vanuatu over the past 50 or so years. Bourke (1999) identifies the most important of these to be higher yielding cultivars of bananas. Bananas have become the most important food staples in a number of locations, including north Malekula, west Epi and parts of north Pentecost. The new banana cultivars have been of Asian origin. There have also been higher yielding varieties of taro, yams and sweet potato introduced and incorporated into the cropping system. The germplasm breeding and distribution project, which is the focus of this case study, has endeavoured to accelerate this process in the face of the pressures created by climatic extremes.

- **Shortening of the fallow period.** According to Bourke 1999, the most common fallow period in Vanuatu is five to ten years. However, in locations under population pressure, the fallow periods are considerably shorter. For example in Middle Bush, Tanna (one of the pilot project areas visited) the fallow periods are now as short as one or two years. This shortened fallow period greatly increases the disease and fertility pressure faced by these highly populated areas.

- **Extending the cropping period.** In conjunction with the shortening of the fallow period, there has been an extension of the cropping period. In the past, just one planting was made before the land was put under fallow. Half of the cropping systems delineated in Bourke's 1999 survey had at least two plantings.

- **Improved fallow species.** Although the fallow periods have been considerably shortened, the value of the fallow has, in some locations, been enhanced by the spread of nitrogen fixing trees such as leucaena.

- **The rehabilitation of ancient irrigated taro ponds.** Bourke's 1999 survey found that in a number of locations, villages are regenerating irrigated taro ponds that have been abandoned for over a century. This regeneration was found to be a direct result of villagers returning from urban centres, in a form of 'reverse depopulation'.

The germplasm breeding and distribution project underpins and strengthens these existing trends in face of the risks created by climate change and climatic extremes.

Public investment in drought and disease tolerant root crop cultivars in Vanuatu

Germplasm surveys and ex-situ (off-farm) germplasm collections in Vanuatu

Vanuatu, as part of a CIRAD lead project, established germplasm collections for yams (*D. alata, D. bulbifera, D.esculenta, D. nummularia*), taro (*Colocasia esculenta)*, sweet potato and cassava at the Vanuatu Agricultural and Technical Centre (VARTC) in Santo. Yams and taro dominate the collection because of their traditional importance. However, there are also significant collections of cassava and sweet potato because of their growing value to village growers.

Camus and Lebot (2010) describe the ex-situ collection that is held at VARTC in Santo:

> Taro: Almost 2300 taro varieties from different countries (Indonesia, Malaysia, Philippines, Thailand, Vietnam, Papua-New-Guinea and Vanuatu) have been characterized. This characterization involved the use of molecular markers which led to the composition of a core sample of 170 varieties introduced in Vanuatu in the form of virus-free *in-vitro* plantlets. Asian varieties are resistant to *P. colocasiae* and resistant genotypes were consequently included in the taro core sample. Blind panel tests of the varieties contributed to the assessment of the organoleptic[20] properties.
>
> Yams: Core samples for the 48 best yam varieties from within the Vanuatu archipelago were assembled. This selection was also based on organoleptic criteria and agro-morphological descriptors. Anthracnose (*Colletotrichum gloeosporioides*)resistance and the shape of tubers were also considered.
>
> Sweet potato: The sweet potato accessions were hybrids between Indonesian and Vanuatu varieties. Indonesian genotypes from CIP (The International Potato Centre) in Bogor (Java) were introduced into Vanuatu

[20] Organoleptic refers to any sensory properties of a product, involving taste, colour, odour and feel. Organoleptic testing involves inspection through visual examination, feeling and smelling of products.

> as true botanical seeds and were crossed with local varieties to produce selected hybrids. Varieties were propagated in VARTC so these hybrid varieties did not exist in the archipelago prior to the study. The selection focused on resistance to scab (*Elsinoe batatas*) and weevils, and on root skin and flesh colour (orange being an indicator of carotene content).
>
> Cassava: Finally, cassava varieties were selected for their organoleptic properties, taste and yield. These were all local varieties originating from different Vanuatu islands.

Moving from ex-situ germplasm conservation to dynamic in-situ (on-farm) conservation

Vanuatu, in common with other Pacific island countries, has had a poor record at preserving germplasm on research stations. Difficulties in ex-situ germplasm conservation extend beyond the Pacific islands, as noted by The FAO Special Information Seminar on" Climate Change and Genetic Resources for Food and Agriculture: State of Knowledge, Risks and Opportunities" held in July 2011, stressed the need for both ex-situ and in-situ conservation and that these had different and complementary roles. The seminar concluded that:

> Among other things, there is increasing acceptance of the ecosystem approach and the concept of ecosystem services in addressing linkages with climate change; that there is a need to strengthen accessibility of genetic resources and availability of information, especially in developing countries; *in situ* and *ex situ* conservation have different but complementary roles in addressing risks and enabling responses; adaptation and mitigation in agriculture should be addressed through an inter-sectoral approach; and recognition that climate change leads to the movement of agricultural biodiversity and creates a need for informed decisions of deliberate movements of germplasm(FAO 2011).

The VARTC pilot in-situ conservation project

In response to three decades of unsuccessful attempts to preserve germplasm on Vanuatu's research stations, CIRAD/VARTC developed a pilot project to test and evaluate on-farm conservation by introducing new germplasm in Vanuatu's traditional cropping systems. The objective of the pilot project was to broaden genetic bases and to include resistance characters while also corresponding to farmers' expectations, in terms of organoleptic and agronomic qualities (Camus and Lebot, 2010, p. 545). The intention of the project was to enrich the varietal portfolios of village farmers, and in so doing, provide protection against future biological disasters and epidemics.

The pilot project commenced in 2005 and involved 10 villages, representative of the diversity of cropping systems throughout Vanuatu. The villages were broadly divided into five 'yam' and five 'taro' villages and are shown in Table 11. The 'taro villages' are located at higher attitude or the moist windward side of islands. Under the project, the taro villages also planted banana, yams, cassava, Fiji taro and sweet potato, in varying amounts. 'Yam villages' used *Dioscorea spp*. as the main crop and are generally located in coastal regions, mostly in the drier areas of the leeward sides. These villages also plant a range of other food staples.

Table 11 Villages participating in the in-situ germplasm conservation project

Village	Island
"Taro" villages	
Pesena	Santo
LaIngetak	Vanua Lava
Metaruk	Pentecost
Lolosori	Aoba
Lamlu (located in Middle Bush)	Tanna
"Yam" villages	
Avunamalai	Malo
Brenwe	Malakula
Ipota	Erromango
Endu	Ambrym
Burumba	Epi

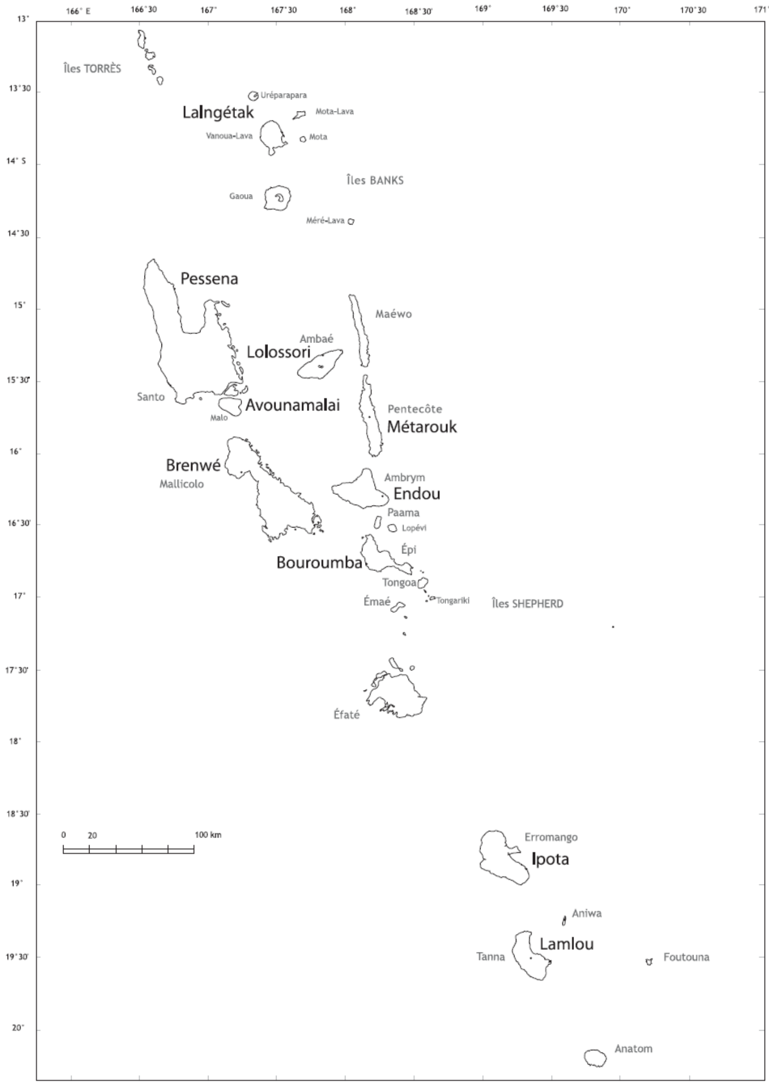
The location of the pilot project village sites is shown in figure 17.

The pilot project commenced with participatory rural appraisals (PRAs) and genetic resource inventories undertaken in each village. The inventories involved detailed counts of traditional varieties within the farmers' fields, to provide a baseline for measuring the genetic diversity created by the pilot project.

Distribution of the VARTC root crop germplasm began in 2005. Considerable effort was made to ensure that varieties were not sent to villages that already had them in their gardens. To facilitate the distribution to widely dispersed remote villages, propagules (planting material[21]) were multiplied at centres on Santo and Efate. VARTC Research Station, Santo, was used for the distribution to the six northern islands (Vanua Lava, Santo, Malo, Aoba, Pentecost and Malakula). The Farm Support Association (FSA) undertook multiplication at Montmartre Plantation on Efate for distribution to the four southern islands (Tanna, Erromango, Ambrym and Epi). There were a total of over 73,000 propagules distributed to the 10 villages (Table 12). The planting material was dispatched in four separate shipments. Taro and yam were sent at the beginning of their traditional cropping cycle (September – November) and sweet potato and cassava cuttings (May – July).

[21] For taro – sucker, yams – tubers, sweet potato and cassava - cuttings

Figure 18 Map of Vanuatu showing location of pilot project sites*



* Source Camus and Lebot, 2010

Table 12 Root crop planting material distributed to the 10 pilot project villages*

Agrosystem	Village	Island	Taro (suckers)	Yam (tubers)	Sweet potato (cuttings)	Cassava (cuttings)
Taro	Pesena	Santo	5815	202	520	1350
	Lalngetak	Vanua Lava	2595	200	520	1350
	Metaruk	Pentecost	5908	184	520	1350
	Lolosori	Aoba	5908	206	520	1350
	Lamlu (Middle Bush)	Tanna	8000	560	2750	3000
Sub-total			28226	1352	4830	8400
Yam	Avunamalai	Malo	2595	446	520	1350
	Brenwe	Malakula	2595	440	520	1350
	Ipota	Erromango	3000	568	2750	0
	Endu	Ambrym	4000	574	2750	0
	Burumba	Epi	3000	530	2750	750
Sub-total			15190	2558	9290	3450
Total			**43416**	**3910**	**14120**	**11850**

* Source Camus and Lebot 2010, p. 546

There were substantial logistical challenges in moving vegetative planting material to isolated villages. As a result, losses in some cases were considerable and the overall costs high. The losses were particularly high for sensitive cassava and kumala. Camus and Lebot describe some of the problems encountered with logistics:

> The number of propagules dispatched from the propagation plots in bags was overall very high, but survival rates were low because of harsh shipping conditions. Many propagules were weakened before their arrival in the villages. They sometimes died during transport or arrived in poor condition. There were also logistical problems: transport conditions were too rough, storage in local airports was too long or local contacts were not properly informed of their arrival (p. 550).

There was also a high degree of wastage due the volume of new planting material that the farmers were required to contend with. Some villages found it difficult to absorb multiple varieties and propagules at the same time. Vincent Lebot indicated losses of up to 80 per cent for some planting material consignments, with overall losses of about 50 per cent (pers. comm.). Regular insertion of new varieties in varietal portfolios is apparently easier for farmers to manage. The delivery of smaller volumes, more frequently, is an important lesson for future distribution programmes. However, this would have had cost implications.

Vincent Lebot estimates the total cost of getting a single propagule to the farmer’s field to be 125 VUV (AUD 1.35). For the estimated 73,000 propagules that were distributed, this represents a total of some 9 million VUV (AUD 70,000). Field maintenance for the six to eight months prior to distribution makes up about 60 per cent of this cost, with inter-island transportation about 40 per cent. These costs do not include any provision for the professional staff involved in plant breeding and management costs. It also does not include the cost of introducing planting material into Vanuatu and assembling material from other parts of the country.

The 2008 assessment of the VARTC in-situ germplasm pilot project

CIRAD undertook an in depth assessment22 of the VATRC pilot project between May–Sept 2008, two years after new germplasm was distributed to the 10 sites (Camus and Lebot, 2010). The intensive field work was undertaken by Pauline Camus as part of her Master's thesis. On-farm quantitative surveys were undertaken to obtain specific information on the adoption of the introduced varieties. Formal questionnaires were used to quantify the various factors that contributed to adoption or rejection of the introduced material.

Data was collected on:

- beneficiary households;
- factors favouring acceptance or rejection;
- the reasons for preservation and rates of losses;
- the propagation rates of introduced varieties;
- the management of the introduced material; and most importantly;
- their circulation within and between communities.

A total of 449 households in the 10 villages participated in the pilot study. Of this total, 316 received planting material23. There were approximately 30 beneficiary households per village. Of the yam villages that received new planting material, 92 per cent of the households kept at least one new variety from at least one of the root crop species. For the yam villages, the retention was 85 per cent. In the taro villages, the number of households possessing some new varieties was twice as high for taros as for the other species. On the other hand, in yam villages, an equivalent number of households kept new taros and yams.

[22]A full week was spent in each village. Even this was regarded as relatively short and necessitated the use of standardized protocols (Camus and Lebot, p. 546). Overall, 449 people were interviewed at the 10 sites and their gardens were visited in order to morphologically identify varieties and to check the information obtained during interviews.

[23]The number receiving planting material should be taken as an approximation. As Camus and Lebot point out, some households from outside the village who received varieties were counted as beneficiaries, eventhough they were not included in the number of households in the village. It is difficult to define the distance atwhich hamlets should be considered to belong to a single village.

Preservation of introduced varieties

The preservation of introduced varieties was measured by comparing the number of traditional varieties present in 2005, with the number of varieties introduced in 2005/2006 and the number of introduced varieties still present in the varietal portfolio in 2008. The study tried to identify the reasons for any losses. The net gain in diversity was estimated by:

- taking into account the number of varieties present in 2005 and those still present in 2008; and
- the number of varieties distributed as part of the study in 2006 that were still preserved in 2008.

There was an impressive 87 per cent net gain in diversity for the yam villages and a 61 per cent gain for the taro villages. Camus and Lebot note that

> Taro varieties that were planted and maintained but not propagated or destroyed were also taken into account. Indeed, in the case of an epidemic, farmers can rely on these varieties, which were abandoned in old gardens. However, this does not apply to yams (especially *D. alata*), which are too fragile to survive without maintenance. Furthermore, the fact that varieties are abandoned or not harvested allows subsequent gene flow because plants left in the ground do flower and enable cross-pollination (Caillon *et al*., 2006; Sardos *et al*., 2008). Thus, enrichment is not only due to the choice to integrate varieties into varietal portfolios but also the enrichment of local agrobiodiversity. Even if introduced genotypes are later eliminated from varietal portfolios, cross-pollination between new varieties and local ones should allow allelic diversification, but this will have to be assessed with molecular markers (p. 547).

Overall, the introduced varieties considerably enriched farmers' varietal portfolios (the number of varieties they actively maintained). For the taro villages, there was a 78 per cent increase in the varieties actively maintained and an 87 per cent increase in the yam villages. Generally, this increase was not at the expense of the existing varieties. There was a particularly high rate of preservation for new yam varieties in villages within the yam-based agrosystems (64 per cent, on average) and for taro varieties in villages within taro-based agrosystems (69 per cent). Table 13shows the preservation rates of introduced varieties (P per cent) and varietal increase rates between 2005- 2008 (V per cent).

Notably, all the existing varieties that were observed in 2005 were still present in 2008, despite the arrival of the introduced varieties. Over 400 of the farmers interviewed confirmed that their traditional varieties were all preserved in 2008 and claimed that they decided to protect their own traditional varieties in spite of the arrival of introduced varieties. The farmers explained that their decision was in keeping with their traditional system of introducing and adopting new varieties without discarding old ones. This finding was consistent with the view that the maintenance of rich diversity is a cultural trait in Vanuatu. Camus and Lebot point out that "the decline of traditional varieties occurs following a reduction in clones planted per genotype, but not to voluntary elimination, so it takes a decade or so before a declining variety disappears completely from all village gardens, according to farmers" (p. 549).

Table 13 The preservation rates for introduced varieties and the varietal increase rates between 2005 and 2008*

	Taro		Yam		Sweet potato		Cassava		Total	
Sites	P%	V%	P%	V%	P%	V%	P%	V%	P%	V%
Taro										
Santo	100	25	31	27	15	50	48	50	51	29
Vanua-Lava	69	93	40	48	46	150	15	31	44	68
Pentecost	28	16	36	68	4	17	4	20	22	28
Aoba	84	50	20	71	8	33	7	22	34	50
Tanna	64	218	73	219	47	371	100	115	64	214
Mean	69	81	40	87	24	124	35	48	43	78
CV%	39	102	50	88	88	119	116	83	38	100
Yam										
Malo	69	540	60	52	8	100	30	160	48	95
Malakula	100	975	81	55	4	33	26	100	62	98
Erromango	17	178	81	93	16	129	–	–	32	85
Ambrym	17	145	25	27	15	80	–	–	18	47
Epi	39	285	71	81	–	–	73	100	52	111
Mean	48	425	64	61	11	85	43	120	42	87
CV%	74	81	37	42	55	47	61	29	41	28

Source: Camus and Lebot (2010) p. 548.

Sociological impact

Based on studies elsewhere, it was hypothesized that communities or whole villages would be better able to maintain a collection of genotypes than individual farmers (Maxted *et. al,* 1997). The pilot study confirmed that the impact on germplasm diversity was greater at the village scale than at the household level, with individual farmers having different portfolios of varieties in their gardens. The propagation rate (number of clones per variety) was highest for taro (propagated by suckers) and sweet potato (propagated by cuttings) and lowest for yam (propagated by tubers).

Reasons for preserving, adopting and propagating new varieties

Farmers were asked to describe the characteristics of the new varieties that they appreciated and those that were not. Taste and texture were found to be the most important positive criteria in the adoption of new varieties. This was confirmed for all species and in each village. Positive agronomic traits (adaptation to the environment and productivity) were valued by farmers but were somewhat less important. However, negative agronomic characteristics were the most important criteria for rejecting a variety. The presence of too many runners on taro was looked at most unfavourably. In the case of yams, small size was often quoted as a reason for rejection. For sweet potatoes, poor yield was a common reason for rejection. Unfavourable agronomic characteristics often relate to the particular environmental conditions into which the material was placed. Yams do not grow well in wet soils and sweet potatoes tend to produce leaves instead of tubers in the presence of excess water. Taro with excessive suckers is, however, a characteristic of Indonesian varieties. These taro varieties were still distributed in order to broaden the genetic base to protect against TLB. The logic is that even if integrated into varietal portfolios only for a short time (tried out) this will allow some hybridization and have an impact on genetic diversity.

Camus and Lebot summarise the farmers selection process as follows:

- when farmers receive varieties, they usually plant them separately from their own varieties;
- if the new varieties respond to agronomic expectations (size, yield, few runners), farmers keep them;
- they then decide to test their cooking characteristics in a traditional way;
- if taste, colour and texture are acceptable, farmers propagate them and replant them; and,
- the more these organoleptic properties are appreciated, the more the varieties will be propagated.

Subsequent distribution of germplasm by farmers

The extent and rate of the distribution germplasm beyond the pilot project participants will determine the eventual overall success of the project. Information was thus obtained when redistribution occurred, to whom and to where, and what and how many varieties were involved.

There was spontaneous distribution of the new planting in all 10 participating villages. Of the households that had maintained new varieties, 40 per cent had distributed at least one of their new varieties to at least one other household. Thus, an additional 238 households benefitted for the project after two years. It was noted that some households did not redistribute varieties because they had not yet propagated sufficient volumes but they intended to do so in future. Some of the new varieties were also distributed without the permission and knowledge of the garden owner. Thus a higher rate of distribution probably occurred than was measured by the study.

The 2011 review of the VARTC in-situ germplasm conservation pilot project

Three of the project sites were visited at the end of May 2011, as part of this study. These were:

Village	Classification
Lamlu (Middle Bush, Tanna)	“Taro” village
Avunamalai (Malo)	“Yam” village
Brenwe (Malakula)	“Yam” village

It was not possible to replicate the detailed in-depth field work of Masters' Student Pauline Camus in 2008. Pauline Camus spent a minimum of a week at each of the sites and undertook intensive structured field interviews with participating farmers. She also undertook comprehensive garden inventories. These visits did however, provide the opportunity to confirm, or otherwise, the findings of Camus and Lebot in 2008.

The three sites were recommended by Vincent Lebot as representing a good cross section of project beneficiaries. Lamlu in Middle Bush Tanna was seen to be of particular interest on account of the high population density of the area and the pressure this is putting on food production. With its taro-based production system, the food security of Middle Bush is under specific threat from the future incursion of TLB.

A full day and a night were spent at each of the three locations. This involved a group meeting with participating farmers. These were followed by individual farmer garden visits. Peter Kaoh, the Manager of the Farm Support Association (FSA), participated in the field visit. FSA have been a partner in the pilot project, being responsible for the germplasm multiplication on Efate. Peter, through FSA's various field programmes, had first-hand experience with all the sites and farmers involved.

Some of the specific findings of the three site visits are discussed briefly below.

Lamlu (Middle Bush), Tanna

The island of Tanna, at 19°30'S, is located well south in the Vanuatu archipelago. Middle Bush is located in the interior of Tanna and is made up of five nakamals (villages), which have a combined population of several thousand people. At an altitude of 400-600 m above sea level, Middle Bush, experiences average monthly cool season minimal of 11-12°C. It is a high rainfall area with an average annual rainfall 3500 mm and is occasionally subjected to acid rain from the Yasur volcano.

Middle Bush faced extreme climatic conditions in 2011, starting with Cyclone Vania in January, with well above average rainfall, continuing through until July. This situation is reflected in the report of the Tafea Province Disaster Committee in June 2011.

> While people from Tanna are still recovering from the cyclone damage, they are now facing another disaster from flooding that began last month. He said that more than 400 people from Tanna's Middle Bush are affected, with the flooding severely damaging most garden crops, plants, animals, roads, and community health. He said with heavy rainfall continuing, roads in the Middle Bush areas are under water along with crops such as island taros, kumala, bananas, and kava and even coffee beans are under threat. Mr Tovurvur said the economy and development of Middle Bush villages are at stake, ruined by weeks of heavy rain. In January, these same communities have faced difficulties after Cyclone Vania destroyed food crops and the heavy rainfall is making the situation worse, he said. Mr Tovurvur said that it will take many months before kava, food crops, plants and coffee beans are ready to earn much needed cash for the farmers. This is the worst flood the old people of Middle Bush have seen (vanuatunews.com, June 5th 2011).

Plate 12 Farmer meeting at the Lamlu nakamal

The field visit to Lamlu was, fortunately, able to proceed as planned. The last week of May was relatively dry and the roads to Middle Bush, although in poor condition, were passable. Despite the extreme weather conditions of the preceding, the six-month food crop gardens visited were observed to be in good condition.

Taro is the dominant traditional crop in this high rainfall location. A total of 8,000 taro suckers were distributed at Lamlu. The distribution included most of the 170 VARTC core sample selection. Discussions with lead farmers and garden visits confirmed a high preservation rate of the introduced varieties and a high maintenance rate of the old varieties. Farmers strongly disapproved of the varieties that produced a large numbers of runners. Our impression is that the increase in genetic diversity measured by Camus and Lebot is being sustained at Lamlu. One garden visited contained 15 taro varieties, including four introduced varieties, which were all clearly distinguishable. This increase in genetic diversity is gradually being expanded to other nearby villages through traditional distribution mechanisms.

Some of the introduced yams are being retained at Lamlu, although clearly at a lower level than for the introduced taro. Unfortunately, some of the preferred introductions of yam were reported to have been destroyed by Cyclone Vania. Farmers are requesting a resupply programme of these preferred varieties. An attractive feature on some of the new yam varieties is that they will re-grow from tubers left in the ground. An increase in the genetic diversity for yams in Lamlu is apparent, but this would seem to be significantly less so for taro and kumala.

Plate 13 Robert Bob with his introduced taro plantings

There is only limited interest in the new cassava varieties, probably due to unsuitable climatic conditions. There is however, a high level interest in the new kumala varieties despite the high rainfall environment of Middle Bush. Most of the new kumala varieties were found to be early maturing (three months) to yield well and to have good taste characteristics. Kumala is becoming increasingly useful in filling the gap in the cropping cycle between December and February when taro and new yams are planted (known as “time hungry”). Some 40 to 50 farmers received kumala cuttings and most have retained at least one kumala variety. One particular farmer had retained all four new kumala varieties he had received - these were all clearly identified in his garden.

Plate 14 Robert Bob with his new kumala varieties

The availability of kumala cuttings from these introduced varieties facilitated rehabilitation following Cyclone Vania. The new kumala varieties can now be found throughout Tanna and are sold on local markets. The rapid spread of kumala, compared with yams and taro, is explained by its lack of traditional cultural significance. Farmers are not possessive about kumala planting material.

Plate 15 Avunamalai farmers village meeting

Avunamalai Malo Island

Avunamalai is a “yam” village located in the interior of Malo. Situated in the rain shadow of the large island of Espiritu Santo, this is a relatively dry location. There are five project participants from Avunamalai, with an additional six participants from the nearby village of Avunaleleo. Most of the gardens are in reasonably close proximity to the village. The main source of cash income is copra, with some cocoa. Some income also now comes from the sale of yams to the Santo market. The new yam varieties have proven popular for sale.

The farmer meeting determined that the staple starches in order of importance are:

1. Yam – usually consumed once a day
2. Banana
3. Fiji taro (xanthsoma)

4. Imported rice
5. Taro
6. Cassava
7. Kumala

Some of the information gleaned from the farmer meeting and garden visits with respect to the introduced varieties is summarised below.

Yams

Approximately 450 yam tubers, made up of 18 varieties, were received in the original distribution. The Avunaleleo farmers report:

Plate 16 A Avunamalai yam garden

- Most farmers maintain at least five of the introduced yam varieties. It is estimated that between 8 and 10 of the 18 new yam varieties have been retained
- There has been no replacement of old varieties. There are some 15 traditional soft yams varieties planted at Avunaleleo
- The introduced varieties included both red and white fleshed varieties —the white varieties are used for custom purposes
- The introduced red varieties were found to have good eating qualities. They were found to have comparable yields to the traditional varieties and to have good storability properties
- The new varieties have been found to be less susceptible to anthracnose
- The introduced yams tended to have smaller tubers which made them suitable for marketing and less desirable for custom purposes
- The introduced yams are sold in the main Santo market for 500 VUV/tuber
- There is prestige associated with having a new yam variety
- Yam distribution on Malo is through custom. Customary yam exchanges on Malo involve the cutting of tubers, which increases the rate of new variety dispersion through the island
- The distribution of other root crop varieties on Malo is not through custom

Taro

- There were around 450 suckers of new taro varieties distributed
- The area is said to be too dry for taro – it was particularly dry in 2004
- The high number of stolons of the new taro varieties was unpopular

Cassava

- There were around 1300 cuttings of eight to nine new cassava varieties distributed
- Four of the new cassava varieties have been maintained in a farmer garden that was visited

Kumala

- Kumala is the least preferred of the root crop staples and no great interest was shown in the introduced varieties
- The climate is suitable but high damage is incurred

Brenwe Malakula

Brenwe is a “yam” village located in Northwest Malakula. This is Vanuatu’s main cocoa growing area. Brenwe farmers earn substantial cash income from high quality organically certified cocoa. Food gardens are located beyond the cocoa and coconuts plantations that surround the village. Four project participants were interviewed. A visit was made to one of the participant’s garden located more than an hour’s walk from the village.

Yam is the main traditional staple but is not consumed on a daily basis. Imported rice is a more important staple in Brenwe than was found to be the case in Malo and Middle Bush Tanna. This is the result of cash cropping — significant cash income is available from cocoa and the relocation of food gardens away from the village.

The information relating to the new root crop varieties obtained from the interviews and garden visit included:

Yams

- Approximately 450 yam tubers (10 varieties) received. All the tubers received were planted. Additional new varieties have been made available through the association of some Brenwe farmers with FSA
- One participant received 10yam varieties and continues to maintain four of these; another planted six new varieties obtained via FSA (yet to be harvested); another obtained four new yam varieties and has continued to maintain two; the fourth participant was not able to obtain new yam tubers the time of original distribution – he only received taro for which there was less demand

Plate 17 Brenwe yam farming system

- The new varieties of yam have been maintained and are well regarded, in terms of taste and yield
- The demand for new yam varieties exceeds availability. The people of this area of Malakula tend to be quite possessive of their yams. Only whole tubers are used in customary exchanges which constrains the rate of distribution of new material
- The Brenwe farmers would like to see another distribution of new yam varieties

Figure 19 New kumala varieties at Brenwe

Taro

- There were 2,500 new taro variety suckers distributed
- There was greater interest in new taro varieties at Brenwe. This contrast with Avunaleleo, the “yam” village on Malo, was that there was limited interest in taro. The greater interest in taro could be attributed to more suitable agronomic conditions
- One farmer originally planted ten new taro varieties and has continued to maintain four; another obtained six and has continued to maintain five (the rejection was due to “itchy” taste)
- Unlike yams, the planting material for the new taro varieties is readily available

Kumala

- Kumala is a new crop for the area
- There is a high level of interest in obtaining new kumala varieties. None of the farmers interviewed obtained kumala cuttings from the original distribution although, some subsequently obtained new planting material from FSA
- One of the farmers who obtained kumala cuttings from FSA is now maintaining six new kumala varieties

Cassava

- Very high damage of cassava cuttings was reported and very little was planted by farmers

Confirmation of broadening of genetic diversity in pilot villages through DNA data

Sardos *et.al* (2011) examined DNA markers for taro from 10 pilot villages. They concluded that the genetic diversity had expanded from 89 alleles, prior to the distribution of the new germplasm to 141 alleles.

Overall conclusions and lessons learnt from the VARTC in-situ root conservation germplasm pilot project

The pilot project has confirmed the interest of ni-Vanuatu village farmers in obtaining new root crop varieties and their ability to manage these new varieties and to expand diversity. This conclusion has recently been confirmed by an examination of the DNA markers for taro from the ten pilot villages (Sardos *et.al,* 2011)[24].

The VARTC Pilot Project has shown that significant impact can be achieved despite the logistical challenges involved with the distribution of perishable planting material in rural Melanesia.

As a result of the Pilot Project, ten reservoirs of genetic diversity have been established throughout Vanuatu. These reservoirs have expanded beyond the Project's original participants. In some situations, traditional cultural practices have accelerated the distribution of germplasm while in others, culture has constrained the rate of distribution.

These germplasm reservoirs provide protection for the participating communities from biological disasters and epidemics of the type experienced by Samoa with taro leaf blight. In the event of biological disaster, these reservoirs would provide a source of immediately available planting material for other parts of Vanuatu. Thus, Vanuatu is in a position to respond more rapidly to such a disaster than Samoa was able to.

There are significant up-front costs involved in establishing and screening the germplasm material for distribution to farming communities. However, once the

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[24] The study concluded "that in 2008, the genetic diversity of taro in Vanuatu was expanded from 89 alleles to a total of 141 alleles, based on the set of SSR markers used in our study".

collection is with the farm community, no additional government or donor resources are required for sustainability. The collection is now imbedded in the local farming system and is maintained by the farmers themselves.

The cost of the Pilot Project is likely to be more justified in its own right. For example, prior to the Project, the arrival of taro leaf blight in Middle Bush, would have had a devastating food security impact on a densely populated area. The cost of such a disaster could be measured in terms of increased imports of rice and acceleration in out-migration to urban Port Vila. However, if the full benefits of in-situ germplasm conservation as a climate change adaptation strategy are to be realized in a reasonable timeframe, consolidation and expansion is now required beyond a pilot project. An outline for such a project is presented below, together with an indicative budget. A comparison of the potential benefits and costs of such project is made.

An outline for a Vanuatu root crop germplasm consolidation and distribution project

Project objective

To substantially expand Vanuatu‘s root crop gene pool to provide protection against biological disasters and epidemics brought about by climate change. This objective is to be achieved through:

- accelerating and expanding the original 10 in-situ germplasm reservoirs created by the pilot project;
- creating new in-situ germplasm reservoirs; and
- selecting from the pilot sites lines/varieties which perform well; these could be linked to the environmental/climatic conditions and therefore be very valuable contributions to the CePaCT climate ready collection.

Management

The project would be managed, under contract, by the Farm Support Association (FSA), with a number of collaborating partners, namely the Department of Agriculture, VARTC, Rural Training Centres, selected high schools and farmer networks.

The selection of FSA as the lead agency is based on the organization’s long standing involvement with farmer networks at the village level. FSA has been a direct partner in the VARTC Pilot Project. They have been responsible for the multiplication and the screening of the germplasm on Efate, prior to its distribution to the sites on Tanna, Erromango, Ambrym and Epi. The Department of Agriculture does not have the same level of experience or interest. Over the years, the FSA has maintained an excellent collaborative relationship with the Department of Agriculture. It is envisaged under FSA leadership that the Department of Agriculture would be active partners. A considerable amount of extension support would be leveraged through the Department of Agriculture.

Duration and phasing

A four year project, with two phases, is envisaged:

Phase 1 (three years)—It would concentrate on areas that are relatively accessible. By way of example the proposed sites would be:

- Tanna (two sites – would include a focus on expanding the Middle Bush germplasm reservoir)
- Santo (two sites – VARTC, Pessena being used as distribution hubs)
- Malekula (two sites – Brenwe being used as a distribution hub)
- Pentecost (two sites – Metarouk being used as a distribution hub)
- Ambrym (two sites)
- Ambae (one site)

The first six months of Phase 1 would involve identifying lead planting material producing farmers who would be responsible for multiplication in their area. During the first six months, two cropping system specialists (one taro system, one yam system) will be identified and trained by VARTC.

Phase 2 (one year)— In Phase 2, the project would expand to Banks and Torres and other more difficult locations

Staffing

Full-time staff

- One coordinator
- Two cropping system specialist field officers (taro system, yam system)
- One administrative assistant

Part-time staff

- Two field assistants

Indicative budget line items

The total cost of such a four-year project is estimated at approximately VUV 67 million (AUD 520,000). The estimated budget line items are presented in Table 14 below. Travel and transportation represent the biggest cost element at VUV 24 million (AUD197,000) or 36 per cent of the total cost. This reflects the high cost of moving people and goods around this dispersed archipelago with relatively poor transportation infrastructure. The next largest line item is personnel cost VUV 19 million (AUD 156,000) or 28 per cent of the budget. The cost of personnel is remarkably low for such a complex four-year project and is a reflection of FSA proven ability to cost effectively implement field-orientated projects.

Table 14 Indicative budget for the Vanuatu root crop consolidation and distribution project

		Vatu
Personnel		
Coordinator	Full time position for 4 years (@ 120,000/month)	5,800,000
Cropping system field officers	2 full time positions for total of 7 years (average of 3.5 years per person) (@90,000/month)	7,600,000
Admin assistant	Full time position for 4 years (70,000/month)	3,400,000
Field assistant	2 part time position for a total of 4 years (average of 2 years per person) (45,000/month)	2,200,000
Sub-total		19,000,000
Travel and transportation costs		
Coordinator	Visits all sites once a year	2,000,000
Cropping system field officers	Visits half the sites (yam sites, taro sites) twice a year	2,000,000
Field assistants	Visits half the sites twice a year	2,000,000
Freight of planting material	Shipping and land transport (based on actual costs for the pilot project)	18,000,000
Sub-total		24,000,000
Planting material costs		
Purchase of planting material from Montmartre and VARTC		5,000,000
Payment to lead farmer planting material producers	Assume 20 led farmer seed producers (5 day/month @ 2000/day for 4 years)	4,800,000
Sub-total		9,800,000
Training costs		
Training of cropping system specialist at VRTC	2 x 3 week visits to VARTC (airfare plus salary/1 person for training period	260,000
Farmer field days	2 field days per site – base on an avg transport cost per participant (100,000 field day)	1,800,000
Sub-total		2,060,000
Communication costs		
Desktop computer plus software		120,000
Mobile phone costs for 5 staff	50,000/month	2,400,000
3 mini laptop computers with flash net for infield internet communication	Estimate at AUD 1,000 each	300,000
Miscellaneous office supplies		500,000
Sub-total		3,320,000
Total cost		58,180,000
FSA overheads	15% of total cost	8,727,000
Grand Total		66,907,000

Comparing the benefits with costs

The Samoa taro breeding programme analyzed in Chapter 3 was an ex-ante response to an epidemic (a biological disaster). The proposed project described above for Vanuatu is a proactive “no regrets” response, impending biological disasters and as climate change is increasing the probability of such disasters occurring, this proactive approach is much needed in the Pacific. The Samoa case study is a good example of how long it can take when action is undertaken in response to a disaster. Countries need to be ready for whatever event climate change throws at them. Both approaches are essential.

Quantifying the impact of future biological disasters in Vanuatu

As with the Samoa case study, the most readily quantifiable means of measuring the economic impact of the loss of a basic food staple is the vatu value of the resulting increase in grain imports. This does not measure the full impact. These are other costs associated with nutrition, loss of income and multiplier impacts on the economy.

It was estimated above that around 20 per cent of food energy needs are supplied by imported food. Grain (rice and wheat flour) make up some 30 per cent of Vanuatu’s imported food (Table 15). It might be assumed that grain accounts for more than half of the imported food energy.

Table 15 Vanuatu’s grain imports (1999 – 2007)

	Rice		Wheat		Total grain imports	Total food imports	Grain imports as a % of total food imports
Year	quantity (tonnes)	value (vatu million cif)	quantity (tonnes)	value (vatu million cif)	value (vatu million cif)	value (vatu million cif)	
1999	10,021	574	3,736	165	739	2,367	31%
2000	10,242	569	3,430	143	712	2,175	33%
2001	11,078	498	3,772	143	641	2,240	29%
2002	10,739	575	3,923	155	730	2,216	33%
2003	10,822	658	3,496	168	826	2,490	33%
2004	11,814	795	4,744	205	1,000	2,756	36%
2005	11,359	691	4,606	190	881	2,863	31%
2006	11,746	833	5,013	220	1,053	3,233	33%
2007	10,951	779	4,798	273	1,052	3,538	30%

Source: Vanuatu Trade Statisitics

Vanuatu currently imports around 16,000 tonnes of grain annually. Over the first half of 2011, the average Cost, Insurance and Freight (CIF)price of these imports was approximately VUV 84,000 per tonne (AUD 653/tonne). The Samoan experience shows the large impact a biological disaster such as TLB can have on grain imports. Table 16simulates the impact of a future impact of a root crop biological disaster on the value of grain imports. The simulations are based on the current CIF price of VUV 84,000 per tonne. However, higher and even more volatile world grain prices can be expected in the future (Christiaensen, 2011).

Table 16 Estimated cost of increases in Vanuatu grain imports (value is given in vatu)

% increase in grain imports	tonnes	value (@ 84,000/tonne cif)
5%	800	67,200,000
10%	1600	134,400,000
15%	2400	201,600,000
20%	3200	268,800,000
25%	4000	336,000,000

It is estimated on this basis that a mere five per cent increase in Vanuatu's grain imports would have a cost of VUV 67 million (AUD 520,000) per annum. A 25 per cent increase would have a cost of VUV 336 million (AUD 2.6 million) per annum. The probability of Vanuatu having a root crop biological disaster over the next decade that results in at least a five per cent increase in grain imports is seen as quite high. Thus, the proposed project that would substantially reduce this probability is seen as an exceptionally worthwhile public investment.

5. Conclusions and recommendations

The high level of food security provided by the traditional Melanesian food gardens is at considerable risk due to the narrow genetic base of traditional root crops. The risks of disastrous epidemics are increasing with climate change and climate extremes.

Vanuatu, in common with other Pacific island countries, has had a poor record in preserving germplasm on research stations (*ex-situ* conservation). As a response to this situation, CIRAD/VARTC developed a pilot project to test and evaluate on-farm (*in-situ*) conservation by introducing new germplasm in Vanuatu's traditional cropping systems. The objective of the project was to enrich varietal portfolios of village farmers, and in doing so, provide protection against future biological disasters and epidemics.

The Pilot Project has confirmed the interest of ni-Vanuatu village farmers in obtaining new root crop varieties and their ability to manage these new varieties and to expand diversity. The pilot has shown that this can be done despite the logistical challenges in distributing perishable planting material in Melanesia. As a result of the Pilot Project, ten reservoirs of genetic diversity have been established throughout Vanuatu. These reservoirs provide protection for the participating communities from epidemics of the type experienced by Samoa with taro leaf blight. In the event of a disease epidemic, these reservoirs provide a source of immediately available planting material for other parts of Vanuatu. Consequently, Vanuatu is now in a position to respond more rapidly to such a disaster than Samoa was able to.

If the full protection benefits of in-situ germplasm conservation are to be realized, consolidation and expansion beyond a pilot project is required. A project is proposed to substantially expand Vanuatu‘s root crop gene pool to provided protection against future biological disasters and epidemics. A four-year project is envisaged that would be managed by the Farm Support Association (FSA), in collaboration with other partners. The total estimated project cost is VUV 67 million (AUD 520,000). The proposed project is a proactive “no regrets” response, impending biological disasters. By substantially reducing the risk of such disasters occurring, the economic returns from such a project are high and make it an exceptionally worthwhile public investment.

Bibliography

Australian Centre for International Agricultural Research (ACIAR), 2008. *Taro Pest: An illustrated guide to pests and diseases of taro in the South Pacific*. Canberra, Australia.

ACIAR, 2011.*Lessons in Diversity for Samoa's Taro Blight*. Plant Protection, Partners, March-May 2011.

Allen, B., 1997. *An Assessment of the Impact of Drought and Frost in Papua New Guinea*, PLEC News and Views, No.9.

Allen, M., 2001. Change *and continuity: land use and agriculture on Malo Island, Vanuatu*, Unpublished M Sc thesis, The Australian National University. Canberra, Australia.

Bailey, John S., 2010. *Climate Change and its Impacts on Agriculture and Rural Society in Papua New Guinea*, National Agricultural Research Institute (NARI).

Benson, C., 1997. *The Economic Impact of Natural Disasters in Fiji,* Overseas Development Institute. London.

Bourke, R.M. and Harwood, Tracy, eds, 2009.*Food and Agriculture in Papua New Guinea*. The Australian National University E Press. Canberra, Australia.

Bourke, R.M., McGregor, A., Allen, M.G., Evans, B.R., Mullen, B.F., Pollard, A.A, Wairiu, M. and Zotalis, S., 2006.*Solomon Islands Smallholder Agriculture Study.* AusAID, Canberra, Australia.
http://www.ausaid.gov.au/publications/pubout.cfm?ID=4088_5412_1071_6193_2813

Bourke, R.M. and Betitis, T., 2003.*Sustainability of Agriculture in Bougainville Province, Papua New Guinea*, Land Management Group, Australian National University.http://rspas.anu.edu.au/papers/lmg/SustainAg_Bvill_text.pdf.

Bourke, R.M., 2010. Altitudinal *limits of 230 economic crop species in Papua New Guinea,* In S.G. Haberle, J. Stevenson and M. Prebble (eds). *Altered Ecologies: Fire, Climate and Human Influence on Terrestrial Landscapes. Terra, Australia* 32.ANU E-Press, The Australian National University, Canberra, Australia.Pp473-512.http://epress.anu.edu.au/terra_australis/ta32/pdf/ch27.pdf

Bourke, R.M., 2000.*Impact of the 1997 drought and frosts in Papua New Guinea,* In *El Niño - History and Crisis.*

R.H. Grove and J. Chappell, eds, 2000.*El Niño: History and Crisis*, White Horse Press. Cambridge, Australia.

Bourke, R.M., 1999. *Vanuatu Agricultural Systems Survey, April-May, 1999*. A Report prepared for the Vanuatu Land Use Planning Project.

Braumann, N., 1998. *New Guinea Drought Update,* Community Aid Abroad.

Bonnemaison, J., 1986. *L'arbre et la pirogue. Les fondements d'une identité: territoire, histoire et société dans l'archipel de Vanuatu (Mélanésie)*. Paris: ORSTOM. (Travaux et documents, n◦201, vol.1).

Brunt, Julia, Hunter, Danny, Delp, Charles, 2001.*A Bibliography of Taro Leaf Blight*, Secretariat of the Pacific Community. Noumea, New Caledonia, April 2001.

Burgess, S., 2006.*Island Climate Update 69 - June 2006Summary of the 2005-06 tropical cyclone season,*Island Climate Update 69 - June 2006 New Zealand National Institute of Water and Atmospheric Research – NIWA.

Caillon, Sophie ,Quero-García, José, Guarino, Luigi, 2004. *Taro in Vanuatu: towards a dynamic conservation strategy,*Leisa Magazine, March 2004.

Camus, P. and Lebot, V., 2010. *On-Farm Assessments of Clonal Production of Root Crop Diversity in Vanuatu, Melanesia*, Experimental Agriculture Vol 46 (4) pp. 541-559, Cambridge University Press, 2010.

Chan, E., 1994.*The impact of taro leaf blight on the Samoan economy and agricultural activity,* Western Samoa Farming Systems Project, Ministry of Agriculture, Forestry, Fisheries and Meteorology, Samoa.8 pp.

Chan, Eddie, Milne, Mary, Fleming, Euan, 1998.*The causes and consequences of taro leaf blight in Samoa and implications for trade patterns taro in the South Pacific region*, Tropical Agriculture, Trinidad, Vol. 75, No. 1, January, 1998.

Collins, Matt, An, Soon-Il , WenjuCai, Ganachaud, A., Guilyardi5, E.,Jin, Fei-Fei, Jochum, Markus, Lengaigne, Matthieu, Power, Scott, Timmermann, Axel, Vecchi, Gabe, and Wittenberg, Andrew , 2010. *The impact of global warming on the tropical Pacific Ocean and El Niño,* Nature Geoscience, Review article Published online: 23 May, 2010. | doi: 10.1038/ngeo868.

Connell, J., 1978. *The death of taro: local response to a change of subsistence crops in the Northern Solomon Islands*, Mankind (No. 11), 445–452.

Christiaensen, Luc, 2011. *Rising to the Rice Challenge: A Perspective from East Asia. An eye on East Asia and Pacific # 10*,World Bank, East Asia and Pacific, Economic Management and Poverty Reduction.

Emanuel, Kerry, 2005. *Increasing destructiveness of tropical cyclones over the past 30 years.* Nature 436, 686-688 (4 August, 2005) | doi:10.1038/nature03906.

Food and Agriculture Organisation of the United Nations, 2008.*Climate Change and Food Security in Pacific Island Countries*, Rome.

Fonoti, Pelenato, 2005. B*reeding Resistance to Taro Leaf Blight (Phytopthora colocasiae) in Samoa*. Masters of Crop Science Thesis, USP, Alafua, July, 2005.

Galanis, Daniel J., Chin-Hong, Peter V., McGarvey, Stephen T., Messer ,Ellen., Parkinson, David, 1995.*Dietary Intake Changes Associated with Post-Cyclone Food Aid in Western Samoa*, Ecology of Food and Nutrition. Vol. 34, pp 137-147.

Government of Fiji, Ministry of Economic Planning, 1999*. Policies and Strategies for the Sustainable Development of the Fiji Islands: A Strategic Plan for the New Century,* Government Printer, Suva, Fiji.

Grove, R. H, 1998.*Global impact of the 1789–93 El Niño*. Nature 393: 318–319.

Hollyer, James R., Sullivan, Jennifer L., Josephson, Margaret, *et. al*,1997. *Taro Mauka to Makai, a Production and Business Manual for Growers of Taro in Hawai'i*, College of Tropical Agriculture and Human Resources, University of Hawai'i.

Hay, John E., 2006.*Climate Risk Profile for Samoa,*In September, 2006.

Hunter, D.G., Iosefa, T., Delp, C.J., Fonoti, P. and Singh, D., 2007.*Participatory evaluation of introduced taro(Colocasia esculenta(L.) Schott) varieties in Samoa,* Tropical Agriculture.

Hunter, D., Pouono, K., & Semisi, S., 1998. *The impact of taro leaf blight in the Pacific Islands with special reference to Samoa,* Journal of South Pacific Agriculture **5**(2), 44–56.

Iosefa, T., & Rogers, S., 1999. *The multiplication, growth and use of introduced tarocultivars in Samoa. Report of an impact assessment carried out during August to November, 1998*, Suva, Fiji Islands: Pacific Regional Agricultural Programme Project 1—Farming Systems in Low Lands.

Jackson, G. V. H., 1999. *Taro leaf blight*, Pest Advisory Leaflet (No. 3), 2 pp. Published by the Plant Protection Service of the Secretariat of the Pacific Community.

Jackson, G. V. H., 1996. *Strategies for taro leaf blight research in the region,* Taro Leaf Blight Seminar Proceedings. Alafua, Western Samoa, 22–26 November,1993. (pp. 95–100). Noumea, New Caledonia: South Pacific Commission.

Jackson, G. V. H., 1977. *Taro Leaf Blight,* South Pacific Commission Advisory Leaflet 3.SPC, Suva, Fiji.4 pp.

Jackson, G.V.H., 1980. *Diseases and Pests of Taro,* South Pacific Commission, Noumea, New Caledonia.

Jansen, T. Mullen, B.F., Pollard, A.A, Maemouri, R.K., Watoto, C. and Iramu, E., 2006.*Solomon Islands Smallholder Agriculture Study. Volume 2*.Subsistence Production, Livestock and Social Analysis. AusAID, Canberra. http://www.ausaid.gov.au/publications/pubout.cfm?ID=4088_5412_1071_6193_2813

Kokoa, P., 1996. *Taro leaf blight in Papua New Guinea: an overview,* Taro Leaf Blight Seminar Proceedings. Alafua, Western Samoa, 22–26 November,1993. (pp. 45–49). Noumea, New Caledonia: South Pacific Commission. Unpublished.

Lebot, Vincent, 2009. *Tropical Roots and Tuber Crops: Cassava, Sweet Potato, Yams and Aroid,* CAB International , UK.

Lebot, V., 1992.*Genetic vulnerability of Oceania's traditional crops,*Experimental Agriculture28:309–323.

Liloqula, R., Saelea, J., and Levela, H., 1996.The *taro breeding programme in Solomon Islands*, Taro Leaf Blight Seminar Proceedings, Alafua, Western Samoa, 22–26 November, 1993. (pp. 143–147), Noumea, New Caledonia: South Pacific Commission. Unpublished.

Maxted, N., Hawkes, J.G., Ford-Lloyd, B.V. and Williams, J.T., 1997.*A practical model for in situ genetic conservation complementary conservation strategies,* In Plant Genetic Conservation: the in situ approach, 545–592 (Eds N. Maxted, B. V. Ford-Lloyd, J. G. Hawkes), London: Chapman and Hall.

McGregor Andrew, 1999. *Root crops and self-sufficiency farming systems.* Vanuatu Land Use Planning Project: Land Use Profiles, Port Vila, Vanuatu.

McGregor, Andrew, R., Bourke, Michael, Manley, Marita, Tubuna, Sakiusa, and Deo, Rajhnael, 2009. *Pacific Economic Bulletin,* Volume 24 Number 2 (2009).

McGregor, Andrew M. and McGregor, Ian K.L., 1999. *Disasters and Agriculture in the Pacific islands*. South Pacific Disaster Reduction Programme (RAS/92/360).

Manner, H.I., and Taylor, M., 2010. *Farm and Forestry Production and Marketing Profile for Taro (Colocasia esculenta)*, In: Elevitch, C.R. (ed.), Specialty Crops for Pacific Island Agroforestry, Permanent Agriculture Resources (PAR), Holualoa, Hawai'i. *http://agroforestry.net/scps.*

Mourgues, A., 2005. *Republic of Vanuatu Environment Profile*, 2004, In NAPA 2007.

NACCC,2007. *Republic of Vanuatu. National Adaptation Programme for Action*, GEF/UNDP/UNFCCC/NACCC, 2007.

New Zealand National Institute of Water and Atmospheric Research – NIWA, 2010.*A new climate early warning system for Samoa,* Asia-Pacific Update 03, Dec 2010.

Packard, J. C., 1974. *The history of the Bougainville taro blight*. Unpublished doctoral dissertation, University of Hawai'i at Manoa, Honolulu, Hawai'i. Thesis for Master of Arts in History, no. 1152.

Paulson, Deborah and Rogers, Steve, 1997. *Maintaining Subsistence Security in Western Samoa*, in Geoforum*, 28:2;* pp.173-187.

Peters, F.E., 1959.*The Chemical Composition of South Pacific foods*. Technical Paper No 115. South Pacific Commission, Noumea, New Caledonia.

Putter, C. A. J., 1993. *Some thoughts on taro improvement in the Pacific*, 12 pp.FAO unpublished report.

Putter C.A.J., 1976.*The Phenology and Epidemiology of Phytophthora Colocasiae Racib. on taro in East New Britain Province Papua New Guinea*, Masters of Science Thesis, Department of Biology, University of Papua New Guinea, Dec 1976.

Raynor, B., & Silbanus, S., 1993. *Ecology of Colocasiataro production on Pohnpei,* In Proceedings of the Sustainable Taro Culture for the Pacific Conference, University of Hawai'i, 24–25 September 1992. (20–24.). Honolulu, Hawai'i: Hawai'i Institute of Tropical Agriculture and Human Resources. HITAHR Research Extension Series No. 140.

Salinger Jim, Allan, Rob, Bindoff, Nathan, Hannah, John, Lavery, Beth, Lin, Z, Lindesay, Janette, Nicholls, Neville, Plummer, Neil and Torok, Simon, 1996.*Observed Variability and Change in Climate and Sea Level in Australia, New Zealand and South Pacific*, In Greenhouse: Coping with Climate Change, ed. Bouma, W.J, Pearson, G.I. and Manning, M.R.,CSIRO Aust. and NIWA NZ.

Samoa Department of Agriculture/Department of Statistics, 1990. *Report on the Census 1989 Agriculture*, Western Samoa.

Samoa Department of Agriculture/Department of Statistics, 2000. *Report on the Census 1999 Agriculture,* Western Samoa.

Sardos Julie, Noyer, Jean-Louis , Malapa, Roger, Bouchet, Sophie and Lebot, Vincent, 2011.*Genetic diversity of taro (Colocasia esculenta (L.) Schott) in Vanuatu (Oceania): an appraisal of the distribution of allelic diversity (DAD) with SSR markers,* Genetic Resource Crop Evol. Published online: 16 July 2011.

Trujillo, E. E., 1965. *Effects of humidity and temperature on zoosporangia production and germination of Phytophthora colocasiae*, Phytopathology,**55**(2), 126.

University of the South Pacific (USP)/FAO. *The Pacific Islands food composition tables*, (second edition.

Vanuatu Land Use Planning Project, 1999. *Land Use Profile: Root crops and self-sufficiency farming systems*, AusAID Land Use Planning Project, Port Vila.

Wall, G. C., 1996.*Life after blight. The current taro leaf blight status on Guam*, Taro Leaf Blight Seminar Proceedings, Alafua, Western Samoa, 22–26November, 1993. (pp. 39–40). Noumea, New Caledonia: South Pacific Commission. Unpublished.

Weitzman, Martin L., 2007.*A Review of The Stern Review of the Economics of Climate Change,* Journal of Economic Literature Vol. XLV (Sept 2007), pp 703-724.