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Food shortages are associated with droughts, floods, frosts and ENSO in Papua New Guinea

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ABSTRACT

In Papua New Guinea extreme climate events have occasionally led to the collapse of normal subsistence food production systems causing large scale food shortages that threaten human health and survival (e.g. during the 1997 El Niño drought). Production of staple foods (e.g. sweet potato) and cash crops (e.g. coffee) are adversely affected by drought, water logging and frost. We investigated the association between El Nino Southern Oscillation (ENSO), extreme climate events and reported food shortages. Over the 120 year period between 1890 and 2009, there have been 15 widespread droughts and 13 of these were associated with El Niño events, and eight of the 12 widespread floods were associated with La Niña events. On a national scale droughts were associated with El Niño systems and wet events were associated with La Niña systems. Since the early 1900s eleven major and widespread food shortages have been reported in the highlands but they have not been associated with drought alone but also with water surplus and frost. Eight of the eleven widespread food shortages were associated with El Niño years (1997, 1987, 1982, 1972, 1965, 1941, 1932, 1911–14) and four of these were preceded by La Niña events (1996, 1971, 1964, 1910). There was evidence of anomalous frosts at lower altitudes (1450 m) and more frequent frosts at higher altitudes (>2200 m) during clear skies in El Niño droughts that also contributed to food shortages. It is a combination of climatic extremes that causes the damage to crops that leads to a shortage of subsistence food in the highlands. The Standardised Precipitation Index provided a useful warning of success of more than 60% for El Niño droughts in 10 of the 18 locations; however the success rates of La Niña flood warnings at these locations was lower (<60%). Using seasonal climate forecasts based on ENSO and climate integrated crop models may provide early warning for farmers, industry agencies and government to help prepare for food shortages. Strategies that can help subsistence farmers cope with extreme climate events and the use, and value of seasonal climate forecast information are discussed.

1. Introduction

The predominance of subsistence agriculture in Papua New Guinea (PNG) highlights the importance of food security (Bourke, 2001, Manning, 2001). Smallholder farmers have generally learnt to manage the localised shortages of food that occur regularly through the use of extended family and purchasing food from the sale of cash crops such as coffee and potatoes. It is the large scale shortages of food that occur irregularly that threaten human health and survival such as during the El Nino Southern Oscillation (ENSO) driven El Niño drought in 1997 (Allen and Bourke, 2001).

During these extreme events (droughts, very high soil moisture levels and frosts) that cause widespread food shortages, the PNG government has relied upon food aid (national and international) and on villagers' self-reliance to purchase imported food. It is the more remote and isolated communities that are most vulnerable because of their poor access to food distribution points and markets to sell produce from cash crops.

Sweet potato is the dominant staple food. It is therefore the most important crop in PNG and over 60% of the rural population depend on it as their main food source (Bourke et al., 2009). However banana, taro, yams, cassava, corn and other traditional vegetables as well as pigs are important dietary components. About 75% of annual sweet potato production is grown in the highlands. Climatic extremes, particularly high soil moisture, droughts and frosts are among the main constraints to production. Sweet potato is relatively drought tolerant. However, excessively wet soil conditions soon after planting of vines followed by drought as the tubers increase in size causes a marked depression in tuber yield and this is commonly attributed to the drought. However it is the combination of climatic extremes that causes the

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damage which can lead to a shortage of subsistence food in the highlands (Bourke, 1988). Repeated frost events also significantly reduces yield of sweet potatoes. Successfully forecasting these events some months in advance could initiate alternative management and avoid significant reductions in yield.

Extreme events (droughts and excessively wet periods) have significant impacts on agricultural production and natural resource management. In the Pacific Rim, including PNG and eastern Australia, the teleconnections (relationship over a long distance) of climate-related anomalies with El Niño and La Niña events are strong and are reliable enough for use in decision making.

Smallholders produce over 90% of the coffee grown in PNG making it a valuable cash crop for many villages. It is grown mainly for export and represents ~40% of all agricultural exports. Although coffee is grown in over 70 countries, the conditions for growing quality beans exist in a relatively narrow climatic range. The optimal climatic regions for growing Arabica coffee are relatively cool climates in the sub-tropical (16–24° N and S latitudes) and equatorial (<10° latitude) zones with the optimum temperature between 15 and 24 °C year round. Photosynthesis is slowed above these temperatures and frost damage can occur when temperatures persist around 0 °C. A large diurnal temperature range is beneficial to coffee quality.

The optimum rainfall for coffee is 1500–2500 mm of rain falling over an 8-month growing period with a 3-month dry season coinciding with the harvest. Where rainfall is less, irrigation can be applied to compensate, although this is not relevant in the PNG context. A period of water deficiency in the soil followed by good rainfall will favour the onset of flowering and produce a homogenous flowering and defined harvesting season. These clearly defined dry and wet events are not common in many areas of the PNG highlands, where a non-seasonal rainfall pattern persists. This can lengthen the flowering and harvesting periods in these areas.

The El Niño Southern Oscillation (ENSO) is associated with warmer than normal water in the central and eastern Pacific Ocean (called El Niño), or cooler than normal water (called La Niña). El Niño is often associated with lower than normal rainfall and because of the dry atmosphere and clear skies during these periods lower minimum temperatures are experienced. La Niña is often associated with higher than normal rainfall and minimum temperatures. These ENSO events commonly commence and cease each year between March and June (Torrence and Compo, 1998, Torrence and Webster, 1998, 1999, Allan, 2000) and persist for 9–12 months. In nearby Australia, the association between the Southern Oscillation Index (SOI) and 3 month Australian rainfall follows a 'predictability barrier' in autumn, builds in winter, reaches a peak in spring and dissipates in summer (McBride and Nicholls 1983; Stone et al., 1996; Chiew et al., 1998, Cobon and Toombs, 2013). Because of the oscillation between El Niño and La Niña, droughts can commonly be followed by floods (and vice versa) (McPhaden, 2003).

Lessons learned from the 1997 drought in PNG demonstrated the vulnerability of agricultural production to climate impacts both in terms of food security and farm income. A review of the current hazard monitoring capabilities and procedures after the 1997 drought recommended development of improved systems that provide early warning of developing threats and regularly updated information on their characteristics and progress. It is therefore a priority in PNG to develop an effective climate forecasting and warning system focussing on drought response strategies, information on quantitative measures of drought and improved crop management practices. Here we report on a project which retrieved long-term rainfall data for PNG, examined its relationship with El Niño Southern Oscillation (ENSO) and investigated the utility of drought warning tools to help maintain food security (sweet potato) and farm income (coffee).

With some reference to sweet potato as a staple food and coffee as a valuable cash crop, the aim of this study in PNG was to:

1. Provide an overview of the influence of climate on the food security of the rural population using the Driver Pressure State Impact Response (DPSIR) model;
2. Source data, develop maps of mean rainfall, percentile maps of annual rainfall, and show the association with ENSO;
3. Examine the number and extent of droughts, floods and food shortages;
4. Use the Standardised Precipitation Index (SPI) to examine success rate and warning length for ENSO triggered droughts and floods;
5. Examine the association between droughts, floods, frosts, food shortage; and
6. Investigate current practices to maximise production and minimise risk through drought management.

2. Materials and methods

The definition of drought in this study is a lack of available water relative to demand resulting from a period of below-average precipitation that may be harmful to crop production at a critical stage of development. Floods are generally described as the overflowing of water onto land that is normally dry and this can cause physical damage to landscapes. However, for the purposes of this study we are more interested in excess water and its impacts in an agricultural context that may occur in the absence of physical damage to the landscape, in particular, the effect that water in excess of soil water capacity and water logging of soil profiles may have on crop production.

The Driver Pressure State Impact Response (DPSIR) (OECD, 1997) provided a framework or process to summarise how the rural population could respond to some of the key drivers threatening food security, including climatic extremes. Using the opinion of experts (extension officers, researchers, industry representatives) and published information we used the DPSIR process to assess the pressures that are most evident, what changes occur in the resources as a consequence, the impacts of those changes and how governments, research funders, extension officers and small holders should respond. In a similar way we investigated climate as one key driver of sweet potato and coffee production and identified the likely pressures, state (resource conditions of importance to production), impacts and responses required by different stakeholders in order to maximise production.

The long term monthly rainfall data were sourced from the PNG National Weather Service (NWS), the PNG colonial data archive (CDA — Bureau of Meteorology Australia), the Coffee Industry Corporation (CIC) at Aiyura and the National Agricultural Research Institute (NARI) at Tambul. The location, elevation and availability of monthly rainfall data for 18 meteorological stations across PNG are shown in Appendix 1ab. Because some stations were moved (e.g. Lae to Nadzab,

Table 1
Percentage area of Papua New Guinea in drought (≤percentile 10 April–March rainfall) or flood (≥percentile 90 April–March rainfall) calculated by the proportion of pixels in the interpolated rainfall surface showing these values.

Year	Area in drought (%)	Year	Area in drought (%)	Year	Area in flood (%)	Year	Area in flood (%)
1997	83.18	1972	41.0	1943	86.7	1985	28.1
1941	83.0	1980	39.0	1907	70.5	1970	24.1
1982	72.9	1931	37.7	1894	47.5	1939	23.9
1914	66.9	1905	32.1	1921	42.8	1925	23.8
1902	61.0	1924	31.7	1998	41.2	1949	23.4
1911	50.3	1965	27.0	1900	39.4	1891	22.6
1987	48.6	1976	27.0	1908	39.0	1964	22.4
1899	43.6	1923	24.7	2000	31.8	1906	22.0
1979	41.1	1993	24.3	1942	31.4	1999	20.3