



‘NextGen’ Projections for the Western Tropical Pacific:

Climate hazard-based impacts for cocoa production in Papua New Guinea

Case Study



January 2022



CSIRO and SPREP (2022). 'NextGen' Projections for the Western Tropical Pacific: Climate hazard-based impacts for cocoa production in Papua New Guinea. Technical report by CSIRO and SPREP to the Australia-Pacific Climate Partnership funded Pacific NextGen Projections project. Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat for the Pacific Regional Environment Program (SPREP). Melbourne, Australia. <https://doi.org/10.25919/9e27-0p69>

This report has been prepared for the Australia-Pacific Climate Partnership (APCP) as part of the APCP-funded project entitled NextGen Climate Projections for the Western Tropical Pacific. The report is based on a sectoral use case led by CSIRO and SPREP, and the authors and contributors to the report are as follows:

Leanne Webb (CSIRO) (Lead)
Kim Nguyen (CSIRO)
Anil Deo (Federation University)
Michael Grose (CSIRO)

The project team would like to acknowledge Kasis Inape (National Weather Service, Boroko, PNG) and Chris Fidelis (Tavilo Cocoa Research Centre, Cocoa Board of PNG) for their helpful advice, and Johanna Johnson (APCP) for her ongoing support through the project.

Dewi Kirono, Kevin Hennessy and Geoff Gooley (CSIRO) kindly reviewed drafts of this report.

Design and layout of the report was coordinated by Kate Morioka and Amanda Opanubi.

© Commonwealth Scientific and Industrial Research Organisation (CSIRO) 2022. To the extent permitted by law, all rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO.

Important Disclaimer

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

CSIRO is committed to providing web accessible content wherever possible. If you are having difficulties with accessing this document please contact csiro.au/contact

Contents

Summary	i
1. Introduction	1
1.1 Reason for conducting this case study	1
1.2 Case studies in the context of NextGen climate projections	1
2. Background	2
2.1 Socio-economic context	2
2.2 Where is cocoa grown in Papua New Guinea?	3
2.3 Biophysical context	4
3. Climate influences on cocoa under current conditions	5
3.1 Stakeholder perspective	5
3.2 Review of literature	5
4. Projected climate hazard-based impacts on cocoa in Papua New Guinea	7
4.1 Will projected increasing temperature conditions affect suitability for growing cocoa?	10
4.2 How does the level of greenhouse gas emissions impact cocoa production in Papua New Guinea?	13
4.3 Will projected average annual rainfall changes affect cocoa production?	15
4.4 How may extreme rainfall projections affect cocoa production?	17
4.5 How may drought conditions change under future climate projections?	18
5. Adaptation: some preliminary notes	19
6. Conclusions and further research	20
7. Methods detail	21
8. References	24
9. Appendix	26



Summary

This is one of several case studies selected to represent various sectors across several different Pacific Island countries. These case studies serve to assist stakeholders in terms of understanding and visualising climate change projections and putting them in relevant context for sectoral applications as part of the *Next Generation Climate Projections for the Western Tropical Pacific*, referred to here as 'NextGen'. The methodological framework used in this assessment can be found in recent reporting by CSIRO and SPREP (2017), with updated guidance by CSIRO and SPREP (2022).

This report is for governments, meteorological services and sector stakeholders in Papua New Guinea (PNG) to use for general communications and policy related questions. The principles and datasets used in this case study can also inform sector impact assessments. **Rather than providing a comprehensive analysis of sectoral impacts, we aim to demonstrate the application of climate projections in a case study. The results are to be used as a guide to inform more detailed assessments.**

Young cocoa trees © SPREP

Key Results

This NextGen case study investigates the impacts of current and future climate change on cocoa in PNG. Cocoa is an important export crop in PNG, providing a significant national economic benefit, and as the industry is a major employer, it also provides an important livelihood benefit. The three major cocoa producing regions in PNG are East New Britain, Autonomous Region of Bougainville (Bougainville) and East Sepik (Bourke and Harwood 2009).

Through recent and ongoing consultation with cocoa producers and relevant industry bodies, using their knowledge and experience of what has been occurring under current climate settings, several climate related impacts were identified.

Ongoing increases in greenhouse gas emissions will cause further global warming and regional climate change (see Table 1). Following a low emissions pathway (RCP2.6) would be consistent with achieving the Paris Agreement target of keeping global warming below 2°C and minimising impacts on PNG, while following a high emissions pathway (RCP8.5) would lead to a global warming of 4.4°C with significant impacts on PNG.

Table 1 Projected changes in PNG (Oceans and Islands) annual temperature and rainfall. Median changes are given, with the 10-90 percentile uncertainty range in brackets. Changes are for 20-year periods centred on 2030, 2050 and 2070, relative to 1986-2005, for low emissions (RCP2.6: green) and high emissions (RCP8.5: red). In 2030, changes are similar for low and high emissions. Source: CSIRO and SPREP (2021)

	2030	2050	2070	1.5°C global warming	2°C global warming	3°C global warming	4°C global warming
Temperature from 1986-2005 (°C)	0.7 (0.5 to 0.9)	0.8 (0.6 to 1.2)	0.8 (0.5 to 1.3)	0.7 (0.4 to 0.9)	0.9 (0.6 to 1.1)	1.9 (1.5 to 2.3)	2.6 (2.2 to 3.0)
		1.4 (1.0 to 2.0)	2.2 (1.6 to 3.2)				
Annual rainfall from 1986-2005 (%)	4 (-3 to 11)	5 (-1 to 16)	6 (-1 to 14)	3 (-5 to 10)	5 (1 to 13)	7 (2 to 22)	10 (2 to 29)
		5 (1 to 17)	9 (1 to 24)				

The potential impacts of projected climate conditions are assessed in this study:

Climate related conditions to be assessed	Cocoa production under future conditions
Will suitable temperature conditions for cocoa (average daily maximum temperatures less than 32°C) be exceeded in future in cocoa growing regions?	Until 2030 the impact of increasing temperature on cocoa production is likely to be minimal - about 60% of the region remains suitable. By 2070, about 80% of the region becomes suitable under low emissions, compared to 55% under high emissions. By 2090, about 80% of the region remains suitable under low emissions, compared to 40% under high emissions.
Fungal disease pressure, e.g. the prevalence of Black Pod Disease can be increased if average annual rainfall is above 2500 mm per year. Is this likely to happen in our cocoa growing regions?	Annual average rainfall is projected to increase 4% by 2030 and 4-7% by 2050. This may increase the incidence of Black Pod Disease in regions with above 2500 mm of rainfall per year. Therefore, the cocoa industry must continue to manage this disease into the future, especially in wet years. The frequency and intensity of extreme daily rainfall events is projected to increase. By 2030, the annual maximum daily rainfall intensity increases 50 mm over Madang and 100 mm over Kavieng and Wewak. This could cause problems for drainage, soil erosion and accessibility to farms.
How will drought conditions change in the future given that more than three months in a row of low rainfall (less than 100 mm/month) is detrimental to cocoa production.	Projected decreases in drought frequency, intensity and duration will be beneficial for cocoa production.
Will changing climate conditions affect the spread of Cocoa Pod Borer?	It is unclear how Cocoa Pod Borer are affected by climate conditions so monitoring this pest carefully will remain important.

The combination of all these impacts is likely to cause some ongoing, and in some cases increasing or decreasing, challenges to the industry due to future climate change in the period beyond 2030, and especially after 2050 if we follow a high emissions pathway. While not reported on here, there will also be indirect or secondary impacts to the industry from a changing climate, including changes to transport and supply chains, national and international markets and so on.

1 Introduction

1.1 Reason for conducting this case study

Cocoa has been identified by the PNG Cocoa Board, PNG Department of Agriculture (regional offices) and PNG National Weather Service as a product with potential for economic development for the country and smallholder farmers. In relation to potential impacts from climate change, the PNG Cocoa Board have expressed significant interest in improving their understanding of the future climate in their region along with the impacts this may have on their crops, products and livelihoods.

Given this interest, as part of the Australian Pacific Climate Partnership (APCP) funded by the Australian Government, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has collaborated with the Secretariat of the Pacific Regional Environment Programme (SPREP) and the PNG National Weather Service (NWS) to undertake this case study. Knowledge from local farmers and producers, scientists and associated sectoral decision-makers was critical in development of this report.

The case study has three goals:

- **Awareness raising** – the results presented here can be used to start discussions and raise awareness of the current and future climate change impacts on cocoa farming for stakeholders in PNG. Training manuals have recently been produced in other countries, e.g. Climate-Smart Agriculture in Cocoa training manual (Dohmen et al. 2018), to help with raising awareness.
- **Climate change impacts** – potential impacts documented here can be used as input to more detailed climate change impact assessments and inform associated analysis of adaptation options and action planning.
- **Provide incentive for the global community to mitigate greenhouse-gas emissions** – in order to demonstrate the benefit of global emissions reductions, this report illustrates impacts for ‘worst case’ and ‘best case’ scenarios which consider high and low global emission pathways. These scope the potential range of projected climate outcomes for the Pacific Island Countries, while also incorporating any beneficial outcomes gained through the global community achieving the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement targets.

1.2 Case studies in the context of NextGen climate projections

The case study presents information from several sources to address the climate related impacts questions identified for cocoa in PNG. For consistency, these are derived from the same set of underlying CMIP5 climate model experiments (Taylor et al. 2012):

- Some new research developed for this report, also demonstrating climate model selection techniques.
- Some new ways for interpreting projected climate hazard-based impacts (also see NextGen country report for PNG – CSIRO and SPREP 2021), adding more sectoral context and detail. These concepts can be found in the green break-out boxes throughout the report.
- To aid more comprehensive reporting, and where relevant to sector stakeholders, we also included results from previous reports (e.g. Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) (Australian Bureau of Meteorology and CSIRO 2011, 2014) to guide the user to the broader range of material currently available to assist in the risk assessment. Refer to the yellow break-out boxes for information derived from other sources throughout the report.

2 Background

2.1 Socio-economic context

While PNG cocoa accounts for less than 1 % of the global production (FAO 2019), the crop represents 17 % of PNG agricultural revenue, or approximately 337 million kina per annum for PNG as of 2015/16 (Anonymous 2017). PNG is the main cocoa producer compared to other countries in the Pacific region; Solomon Islands, Vanuatu and Samoa, with both Fiji and Federated States of Micronesia (FSM) also producing cocoa, but to a much lesser extent (Figure 1) (FAO 2019).

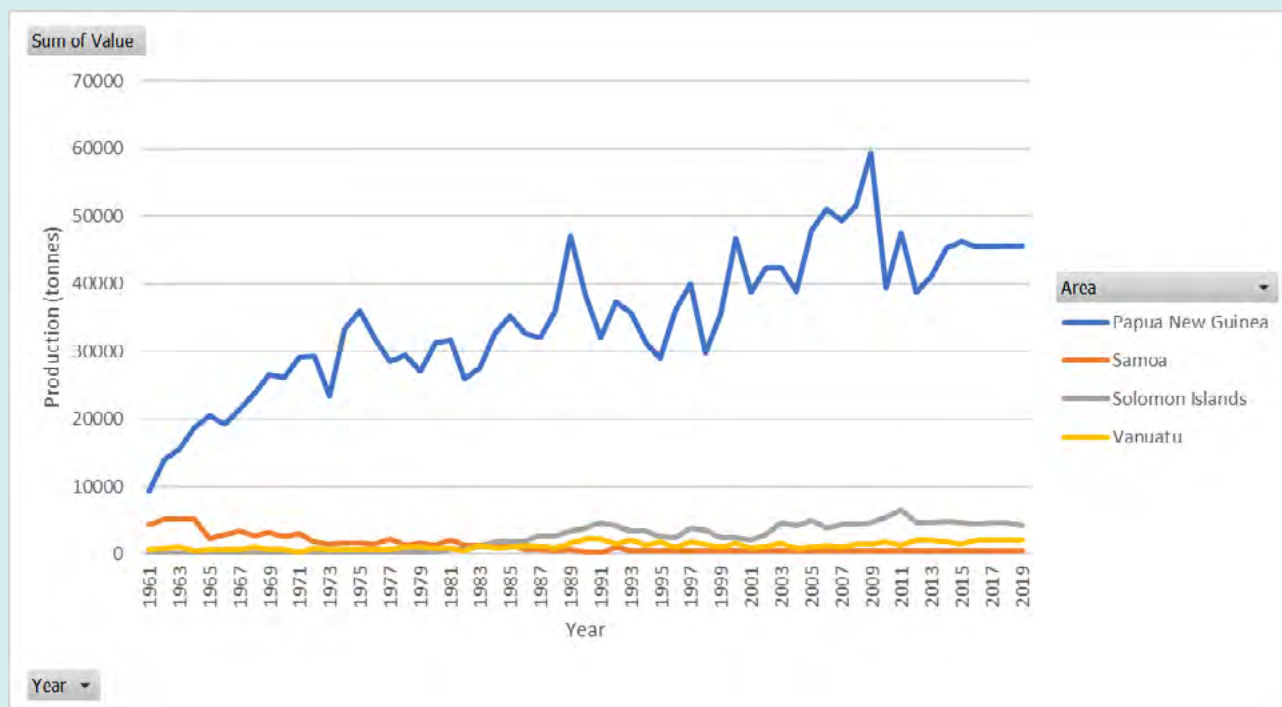


Figure 1 Cocoa production trends in the Pacific (data source FAO (2019)).

Cocoa is a significant cash crop for rural villages in PNG, third after coffee and fresh food (Bourke and Harwood 2009), sustaining around 151,000 families, or approximately two million people (Nelson et al. 2011). With PNG plantation production systems declining in prominence since the 70's (Bourke and Harwood 2009), cocoa is now mainly produced in low input - low output farming systems (Curry et al. 2009). Indeed, in PNG around 80 % of cocoa is produced by small, family-owned farms (Nelson et al. 2011), 1-2 ha in size (Reynolds et al. 2019).

Since the 1960s, both production and land area devoted to cocoa has been increasing, though yields have been declining since high levels in the 1970s (Figure 2) (FAO 2019). From around 2010, some of the decline in average yields has been attributed to the establishment of the Cocoa Pod Borer, a highly destructive insect pest, in the cocoa production areas in PNG (Pearce 2016).

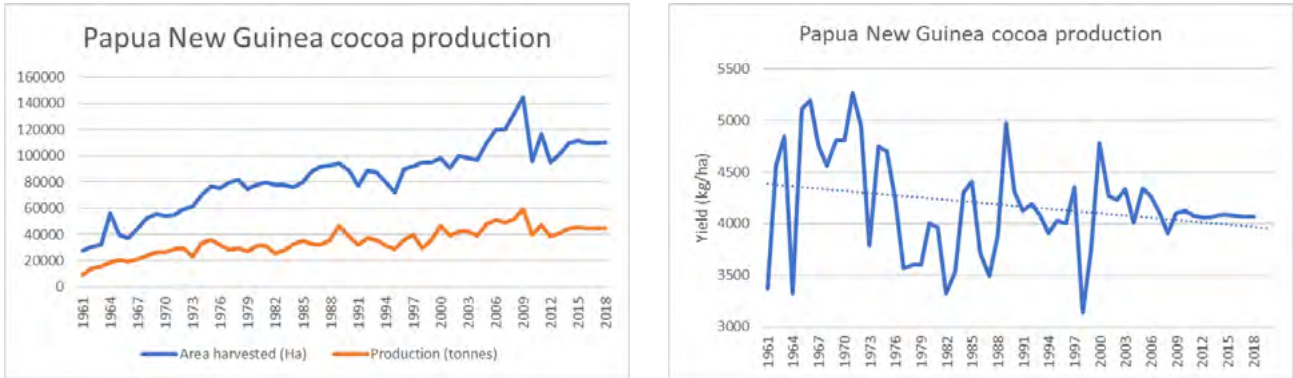


Figure 2 Cocoa production and area harvested (left), and yield (kg/ha) with linear trend (right), in PNG. Data source: (FAO 2019)

2.2 Where is cocoa grown in PNG?

Until 1977, the national production of cocoa (*Theobroma cacao* L.; Malvaceae) was dominated by the plantation sector based in Bougainville, East New Britain, New Ireland and Madang provinces (Hanson et al. 1998). Currently, the three major cocoa producing regions are East New Britain, Autonomous Region of Bougainville (Bougainville) and East Sepik (Bourke and Harwood 2009), however 14 of the 20 provinces in PNG grow cocoa; mainly in wet lowland areas (Figure 3). Lately, the crop is being trialled in the highlands (Reynolds et al. 2019).

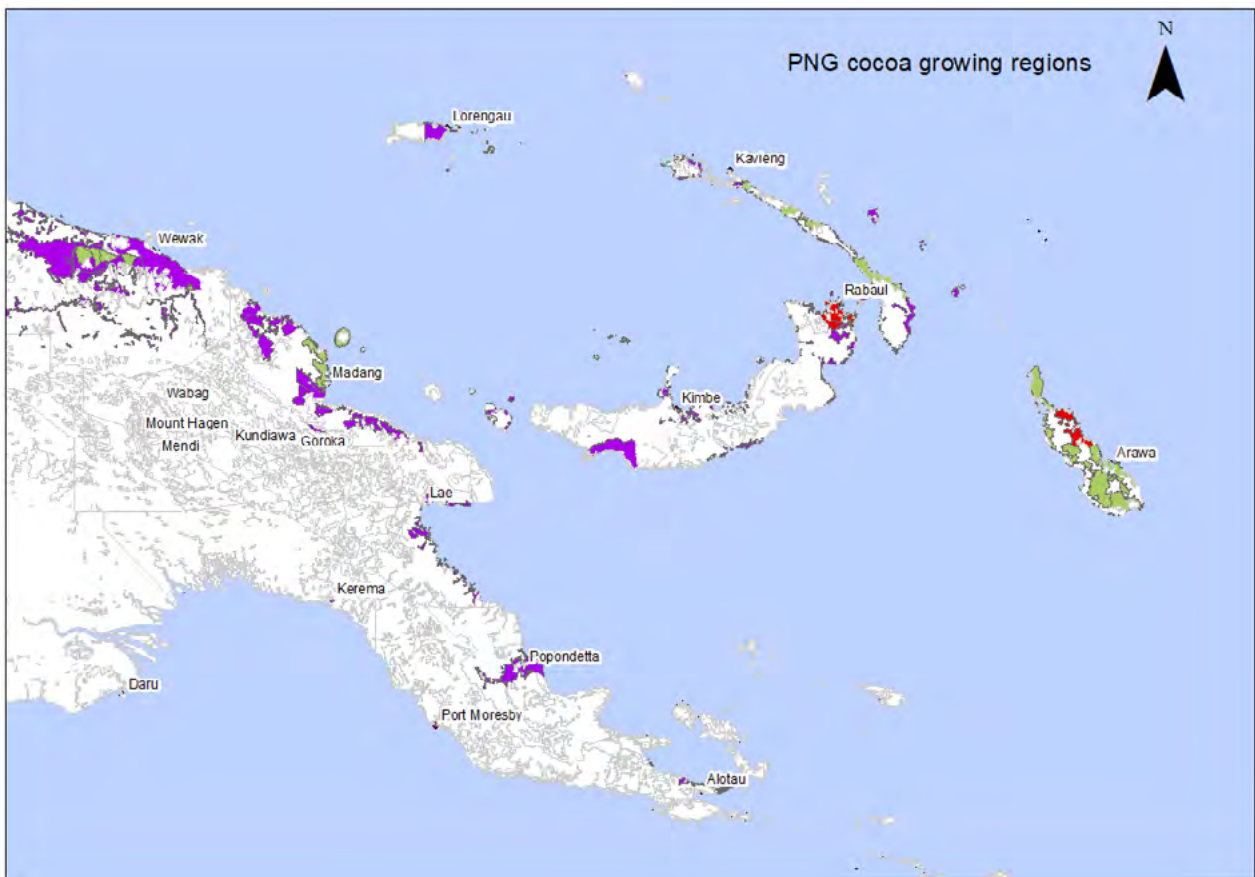


Figure 3 Map of PNG with regions where cocoa is grown: Minor or insignificant (purple), Significant (Green), Very significant (Red) and districts outlined in grey as described in Bourke et al. (1993).

2.3 Biophysical context

Climate

Sites in PNG have very weak seasonal variations in temperature (Figure 4). The south of PNG has a wet season from November to April and a dry season from May to October, e.g. Port Moresby, while further north rainfall is more consistent throughout the year, e.g. Kavieng. Rainfall in PNG is influenced by the West Pacific Monsoon. High year-to-year variability in rainfall is mostly due to the impact of the El Niño-Southern Oscillation (Australian Bureau of Meteorology and CSIRO 2011).

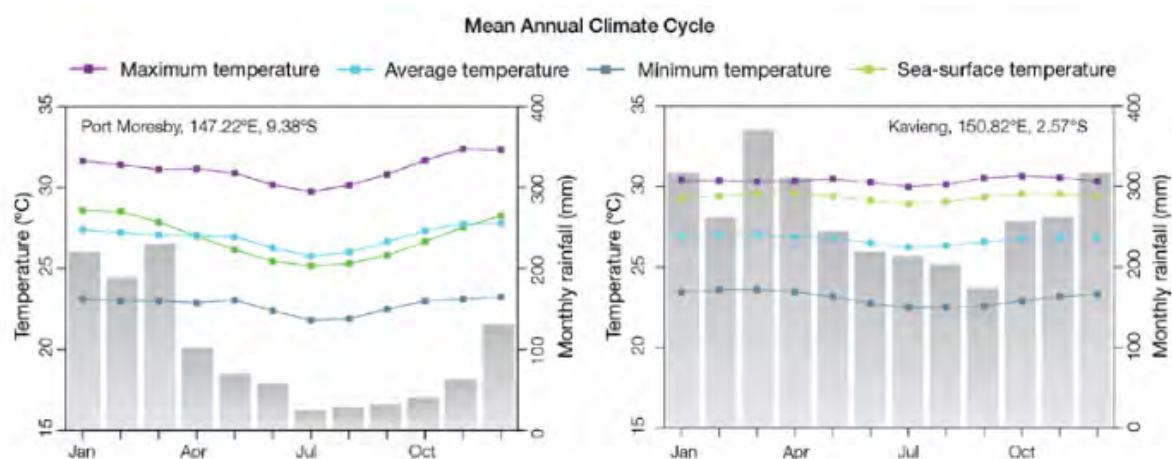


Figure 4 Mean annual cycle of rainfall (grey bars) and daily maximum, minimum and mean air temperatures at Port Moresby (left) and Kavieng (right), and local sea-surface temperatures derived from the HadISST dataset (Australian Bureau of Meteorology and CSIRO 2011)

Cocoa pests and diseases

Cocoa Pod Borer (CPB) moth (*Conopomorpha cramerella*) (Figure 5, left), first discovered in East New Britain in 2006 (Reynolds et al. 2019), has resulted in reduced yields with effectiveness of the normal low-input farming practices being questioned across the industry (Curry et al. 2015). As no indication of a relationship between climate and the incidence and spread of Cocoa Pod Borer has been reported in the literature (Taylor et al. 2016), the likely impact of future changing climate conditions on CPB is unclear (Taylor et al. 2016). In the light of this limited understanding, improved monitoring of this pest, including identifying and evaluating more preventative approaches and management options for their control is more essential than ever (Taylor et al. 2016).



Figure 5 Cocoa pod, destroyed by Cocoa Pod Borer (Creative Commons Attribution-Share Alike 4.0 International license) (left) and cocoa pods infected with Black Pod Disease (Creative Commons-Non-Commercial-Share Alike 2.0 Generic) (right)

Cocoa Black Pod Disease (CBPD) (Figure 5, right), a fungus affecting Solomon Islands cocoa producers, has increased incidence under higher rainfall conditions (Taylor et al. 2016). To date this disease has been effectively controlled in PNG so is not seen as a problem (Chris Fidelis, Pers comm).

3 Climate influences on cocoa under current conditions

3.1 Stakeholder perspective

A workshop held in PNG November 2020 was attended by Tavilo Cocoa Research Centre, Cocoa Board of PNG, NWS, and other relevant parties (see Appendix), and had the following objectives:

1. Present information included in this report about current knowledge and potential impacts from projected climate change for cocoa farming in PNG.
2. Discuss mechanisms and opportunities to communicate this climate change information to stakeholders for decision-making and planning.

The workshop acknowledged that this case study has included relevant metrics and thresholds for assessing climate hazard-based impacts for cocoa production in PNG.



Young cocoa trees © SPREP

3.2 Review of Literature

A literature search reveals that there is a good deal of relevant general information about cocoa production in PNG (Bourke and Harwood 2009), a very relevant chapter in the book by the Secretariat of the Pacific Community (SPC) on climate change and agriculture (Taylor et al. 2016), and detailed analysis of the climate envelope for cocoa in Africa (Davis et al. 2012). The literature review and engagements with key stakeholders identified the following key climatic variables that may influence cocoa production:

- Temperature
 - Cocoa grows best below a mean maximum temperature range of 30°C – 32°C, a mean minimum temperature range of 18°C – 21°C; and an absolute minimum of 10°C (Wood and Lass 2008).
 - Cocoa is sensitive to prolonged periods of high temperature, especially if coinciding with limited water availability (Taylor et al. 2016). Constant temperatures above 31°C have been associated with a loss of apical dominance and numerous flushes with small leaves produced by the axillary buds. With diurnal temperature variation, i.e. cooler nights, this loss of apical dominance does not occur (Wood and Lass 2008).
 - Taylor et al. (2016) suggest that high temperature events will be more problematic in areas where maximum temperatures are already high; e.g. East New Britain, Bougainville and Malaita.

- Rainfall
 - Wood and Lass (2008) report that cocoa is grown where rainfall is 1250–3000 mm per annum, preferably between 1500–2000 mm, while Hanson et al. (1998) suggests annual rainfall of 1800-2600 mm, and Bourke and Harwood (2009) indicate 1800 mm to over 5000 mm. Increased pressure from Black Pod Disease (*Phytophthora palmivora*), while currently well controlled in PNG, is increased if rainfall is above 2500 mm per year. For this assessment we discuss the chance of future rainfall totals exceeding 2500 mm in PNG.
 - Cocoa prefers a dry season of not more than three months with less than 100 mm rain per month (Wood and Lass 2008)
 - Extreme rainfall may increase risk from Cocoa Black Pod (*Phytophthora palmivora*) disease. While not a problem in PNG currently, potential climate shifts may increase pressure from this fungus in future.
 - Extreme rainfall may cause water-logging and erosion, and reduce access for farmers due to flooding.
- Drought
 - Long periods of drought will cause cocoa buds to wither, resulting in reduced yields (Taylor et al. 2016)
- Tropical cyclones
 - Most of the world's cocoa producing areas are not prone to cyclones, including PNG. This is not the case for the other Pacific cocoa producing countries, such as Solomon Islands, Vanuatu, Samoa and Fiji (Taylor et al. 2016).

This case study examines some of these factors with regard to both positive or negative impacts on the cocoa industry in PNG. However, there are many other climate and non-climate related issues that need to be assessed before the overall climate hazard-based impacts can be understood.

Other climatic influences:

- High wind speed is detrimental to flowering / seed gardens in nurseries. Cocoa does not grow well where there are persistent strong winds (Wood and Lass 2008).
- Solar radiation and humidity.

Non-climatic influences:

- Farm management practices (e.g. shade trees (Dohmen et al. 2018)) and the cocoa supply chain (processing, storage, transport, etc.).
- Conservation practices, e.g. rainforest protection (Bisseleua 2019).
- Worker productivity and a range of other relevant socio-economic factors affecting the practices, livelihoods and wellbeing of smallholder cocoa production.
- Cocoa Pod Borer (CPB), *Conopomorpha cramerella*, is a major problem affecting production in PNG, however links to climate or climate variability are not known.
- Age and senility of cocoa plantings.
- Decline in government extension services, poor credit services, disputes on land ownership.
- Smoke tainted cocoa beans.
- The relative advantage or disadvantage of the PNG cocoa industry compared to production in other developing countries (Latin America and the Caribbean, with African countries' production also contributing a significant proportion).

The climate in PNG's cocoa-producing areas is more uniform than the cocoa areas of West Africa and South America (Wood and Lass 2008). In areas such as the Gazelle Peninsula, East New Britain and Bougainville, rainfall tends to be well distributed with no dry months. Further, temperatures vary only slightly and tend to be one or two degrees higher than those in other major cocoa-producing countries (Taylor et al. 2016).

4 Projected climate hazard-based impacts on cocoa in Papua New Guinea

Stakeholder survey responses and scientific literature reviews informed our approach when considering future projected climate, and led to the identification of the following research questions:

1. How will the maximum temperature conditions for growing cocoa be affected under future climate change scenarios?
2. How does the level of greenhouse gas emissions impact cocoa production in PNG?
3. Under future climate change, could the average annual rainfall become too high, or could there be too many / too few dry months for growing cocoa in PNG?
4. How will extreme rainfall events affect disease risk and access to cocoa farms?
5. How may drought conditions change under future climate projections?

Methods outline

Spatial interpretation of current and future cocoa production conditions are explored here using a GIS mapping platform. Current climate conditions for a 30-year period centred on 1995 (1981-2010) are shown contrasting with a range of future climate options that illustrate both 'best case' (or least change), and 'worst case' (or most change) climate for the a 30-year period centred on 2050 (2036-2065). These future climate scenarios were presented to indicate the range of potential climate-hazard related impacts to which cocoa production may be exposed. (See Methods details and data section at the end of this report).

Where relevant in explaining the analysis and assessment of the above questions, NextGen information 'Boxes' are included throughout the report (See NextGen country report for more details – CSIRO and SPREP 2021)

NextGen Climate Projection Information Boxes:

- Box 1** 'Worst case' and 'best case' scenarios
- Box 2** Projected change: near term, medium term and long term
- Box 3** Near-term variability and change

Box 1: 'Worst case' and 'best case' scenarios

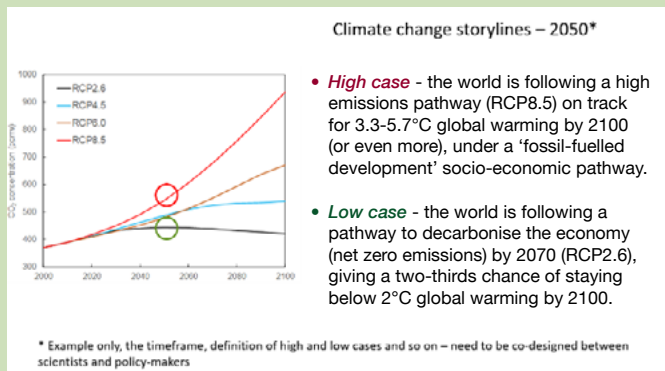
The various scenarios of possible future climates are affected by

- global greenhouse gas and aerosol emissions pathways
- regional climate responses to each emissions pathway
- ongoing natural climate variability.

The 'emissions' component, often referred to as Representative Concentration Pathways (RCPs) (Van Vuuren, 2011), must be framed as possible scenarios of human development and actions.

The 'response' component needs an analysis of various lines of evidence including how the climate responds to those emissions according to Global Climate Model simulations. For each emissions pathway, the main two dimensions of the broader climate response are the amount of global warming in response to the emissions (measured globally as 'climate sensitivity'), and the change to regional circulation and weather systems (the 'dynamical' change). Simulations from different climate models can be used to assess the range of change in each of these parts of the story.

The table below shows projected changes in PNG annual temperature and rainfall. Median changes are given, with the 10-90 percentile uncertainty range in brackets. Changes are for 20-year periods centred on 2030, 2050 and 2070, relative to 1986-2005, for low emissions (RCP2.6: green) and high emissions (RCP8.5: red). In 2030, changes are similar for low and high emissions.



	2030	2050	2070	1.5°C global warming	2°C global warming	3°C global warming	4°C global warming
Temperature from 1986-2005 (°C)	0.7 (0.5 to 0.9)	0.8 (0.6 to 1.2)	0.8 (0.5 to 1.3)	0.7 (0.4 to 0.9)	0.9 (0.6 to 1.1)	1.9 (1.5 to 2.3)	2.6 (2.2 to 3.0)
		1.4 (1.0 to 2.0)	2.2 (1.6 to 3.2)				
Annual rainfall from 1986-2005 (%)	4 (-3 to 11)	5 (-1 to 16)	6 (-1 to 14)	3 (-5 to 10)	5 (1 to 13)	7 (2 to 22)	10 (2 to 29)
		5 (1 to 17)	9 (1 to 24)				

Ripe cocoa © Skia website <https://www.skia.ws/gallery/>

When planning to inform adaptation strategies for the future it is strongly recommended to consider a range of *plausible future climate outcomes* with regard to the influence of climate:

1. **Best case scenario** – representative climate model CNRM-CM5 with a low emission pathway RCP2.6. This gives a lower warming over PNG with little change in rainfall (Figure 6, left).
2. **Worst case scenario** – representative climate model GFDL-CM3 with a high emission pathway RCP8.5. This gives a higher warming over PNG with a wetter climate (Figure 6, right).

The temperature and rainfall changes simulated by all available climate models between the baseline and future period can be plotted as a 2D shape that describes the range of change for both the **Low Case** and **High Case** emission pathways. The two different scenarios – hot/wet and warm/little rainfall appear in diagonally opposite corners of each shape:

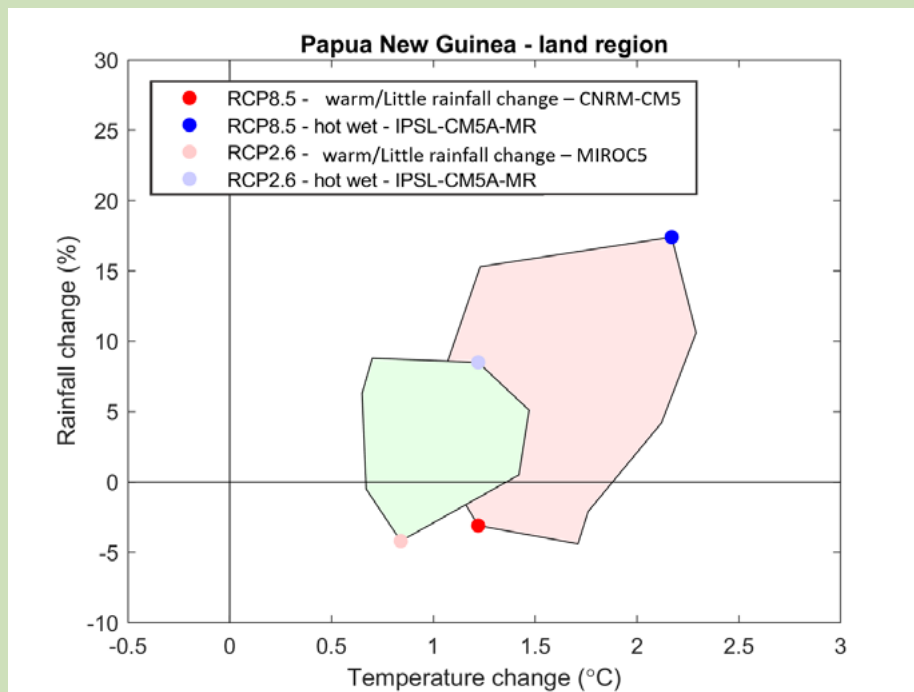


Figure 6 Simulated change in annual temperature and rainfall in the PNG region between 1986-2005 and 2040-2059 from CMIP5 models (coloured shapes), showing the selected climate models that are representative of a warm/little rainfall change future or best case scenario (CNRM-CM5) and a hot/wet future or worst case scenario (GFDL-CM3). Source: <https://www.pacificclimatefutures.net/en/climate-futures/future-climate/>.



4.1 Will projected increasing temperature conditions affect suitability for growing cocoa?

The climate has already warmed in PNG (McGree et al., 2019) and further warming is expected (e.g. 0.5-0.9°C by 2030, relative to 1995), but after 2030 there is a growing difference in warming depending on the greenhouse gas emissions pathway the global community follows (Figure 7).

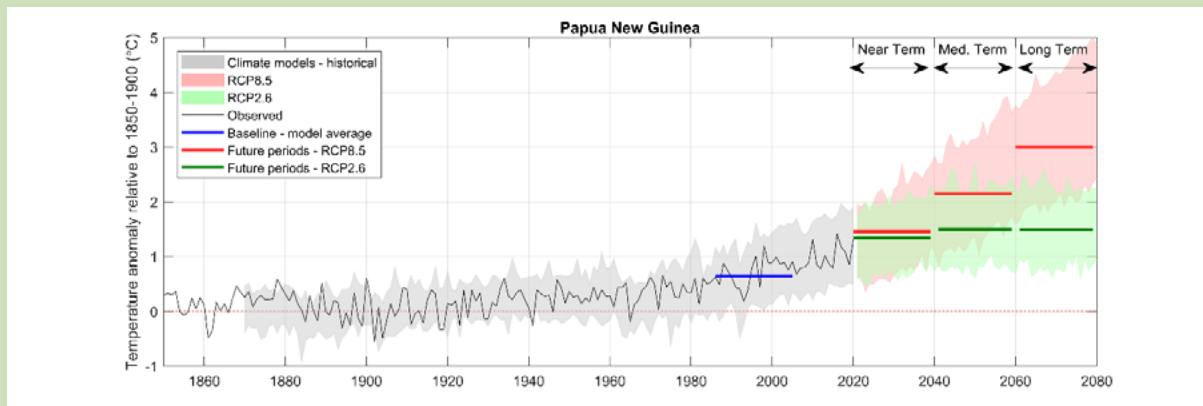


Figure 7 Average annual temperature in PNG relative to 1850-1900 (°C) derived from observations (Berkeley; grey solid line) and simulated in CMIP5 models, showing the range of all models for the past period (grey band), and the future under a very high emissions pathway (pink band) and a very low emissions pathway (green band). Thick horizontal lines show the mean of 40 models in the 20-year baseline period 1986-2005 (blue line) and future 20-year periods centred on 2030, 2050 and 2070 (RCP8.5; red lines, RCP2.6; green lines). Source: CSIRO and SPREP (2021)

In accordance with reviews of the literature and feedback from stakeholder engagement, this NextGen assessment defines the suitable¹ area for growing cocoa under a current climate where annual-average maximum temperatures are below 32°C. For the current climate 1995 (1981-2010), this area is indicated with the green shading in Figure 8 (right panel).

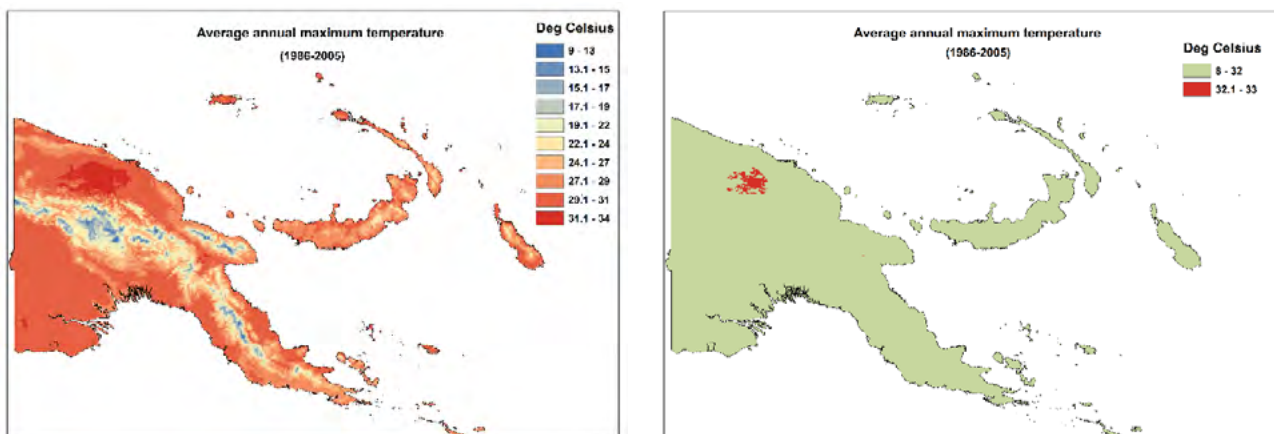


Figure 8 PNG annual maximum temperature (°C) averaged over 1981-2010 (left) (Source: Modified WorldClim, see Methods details). Corresponding climate suitability for cocoa production (right). Suitable is < 32°C (green), not suitable is > 32°C (red).

¹ Suitable is defined as areas where the average maximum temperature is below 32°C.

To estimate the suitability for growing cocoa in the climate centred on 2050, it is prudent to consider the potential range of projected temperatures. Currently only 3% of the PNG region is too warm for cocoa, but by 2050 the 'best case' has 17% too warm and the 'worst case' has 49% too warm (Table 2).

By 2050 (2036-2065), suitability for cocoa farming under the 'best case' scenario (a low emissions pathway and least warming model) indicate some areas that are currently suitable for will become too warm, i.e. more red shading (Figure 9; top-left). When the low emissions pathways is combined with a high warming model, the area with red shading is slightly larger (not shown).

By 2050 (2036-2065), under the 'worst case' scenario, with a high emissions pathway and high warming model (Figure 9, bottom-right panel), many areas that are currently suitable will become too warm. This could become an important limiting factor to cocoa growing by 2050.

Table 2 Percent of PNG region with suitable annual average temperature for cocoa by 2050 (2036-2065). These calculations are drawn from the 'best case' scenario (CNRM CM5, RCP2.6) and 'worst case' scenario (GFDL-CM3, RCP8.5) with emissions pathways and time periods as indicated.

Percent of PNG cocoa district	Current (1981-2010)	Best case 2050 (2036-2065) (CNRM CM5, RCP2.6)	Worst case 2050 (2036-2065) (GFDL-CM3, RCP8.5)
Suitable (< 32°C)	97	83	51
Too warm (> 32°C)	3	17	49

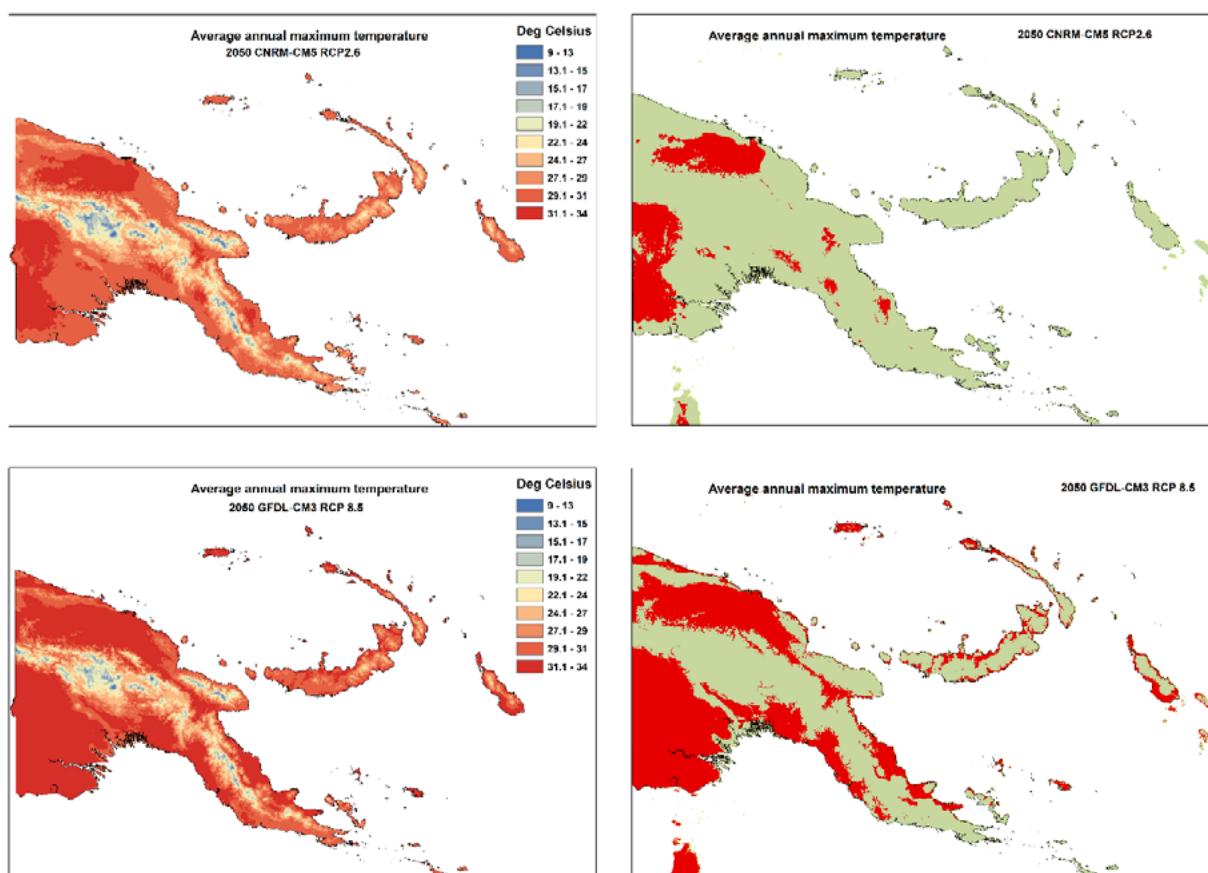


Figure 9 PNG projected annual maximum temperature (°C) for 2050 (2036-2065) under 'best case' (lower warming model and low emissions; upper left) and 'worst case' (hot/wet model and high emissions; bottom left) climate scenarios. Corresponding temperature suitability for cocoa production (right): suitable is < 32°C (green), not suitable is > 32°C (red).

The suitability for cocoa production within the current global centres of production may seriously decline by 2050 (Läderach et al. 2013). As the average temperature of the main Pacific cocoa-producing areas of East New Britain, Bougainville and Malaita is several degrees above that of the main West African and South American cocoa producing areas, it is likely that increasing temperatures will impact on cocoa production in PNG at an earlier time than the world's major cocoa-producing areas. In contrast, Vanuatu, Samoa and Fiji can expect to be relatively favourably placed for cocoa production as the current climate in these areas is cooler than that in West Africa and South America (Taylor et al. 2016). In the longer term, should average temperatures increase by more than 2°C, areas in Tonga could become suitable for cocoa production (Taylor et al. 2016).



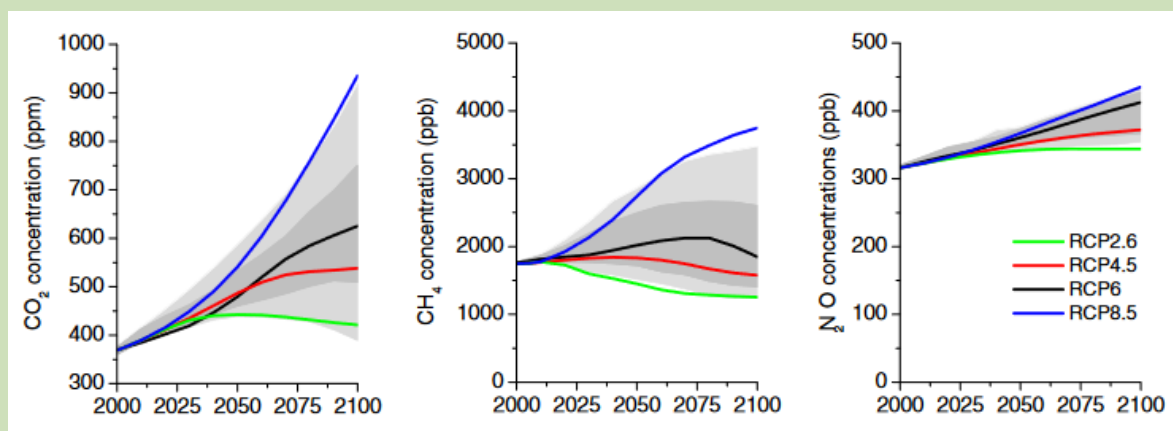
Drying cocoa © SPREP

4.2 How does the level of greenhouse gas emissions impact cocoa production in PNG?

By 2030, average climate changes will be similar under all emissions pathways. After 2030, different emissions pathways start to make a difference to the climate response, and therefore the related impacts (Figure 10).

Box 2: Projected change: near term, medium term and long term

Greenhouse gases (GHG) have a warming effect. The main greenhouse gases are water vapour, carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Human activities such as burning fossil fuels, agriculture and land-use change (e.g. deforestation) have increased GHG concentrations in the atmosphere. GHGs have a long lifetime in the atmosphere, so GHGs emitted today remain in the atmosphere for decades to come and it is not until a few decades have passed that differences in atmospheric concentrations will become apparent as seen in the graph below (Van Vuuren et al. 2011).



Projected temperature changes evolve in a similar way for PNG: under the high emissions pathway in the pink shaded band (RCP8.5), and a low emissions pathway in green (RCP2.6), with the model averages shown as thick lines. In the near term (2020-2039) the range of projected temperature change is similar for both emissions pathways, but in the medium term (2040-2059) the pathways begin to separate, and by the long term (2060-2079) the pathways give very different outcomes. By 2080, there is almost no overlap. Given the long lifetime of greenhouse gases in the atmosphere, early actions taken to reduce emissions by the global community can slow the rate of climate changes experienced. (NB these changes are relative to the pre-industrial 1850-1900 period, different to the PACCSAP baseline of 1986-2005).

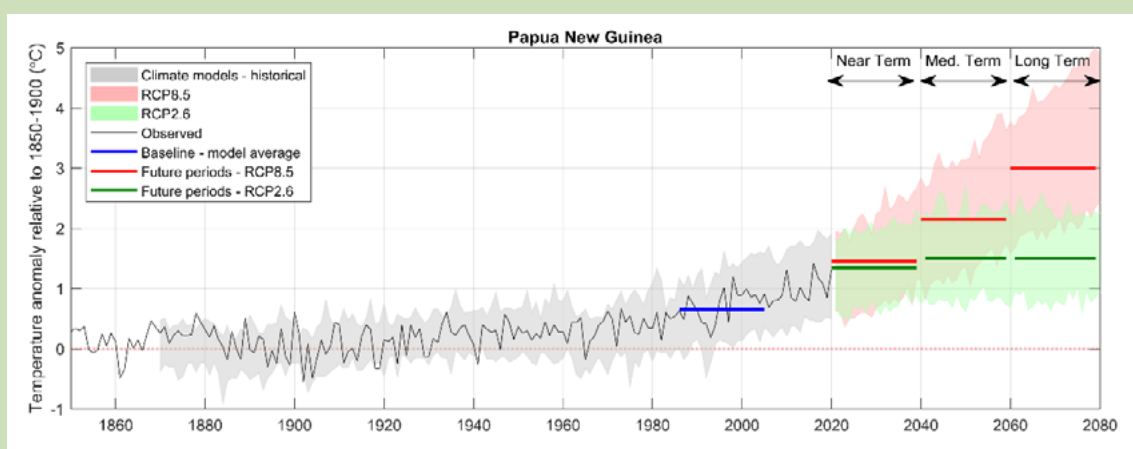


Figure 10 Climate model representation of historical and projected temperature time-series anomaly (cf. 1850-1900) for PNG (Mainland region). The observed temperature time-series anomaly (black line) superimposed on the 40-CMIP5 model representation of past climate (grey band) and projected temperatures to 2080 and under RCP8.5 (pink shading) and RCP2.6 (green shading). Red and green bars indicate the 40-model mean for 20-year periods, showing the growing difference in the projections into the future as described under the different RCPs, and the remaining overlap of model range between the two (CSIRO and SPREP, 2021)

There is hardly any difference in the impact of climate change on cocoa suitability under both lower and higher emissions pathways by 2030 – about 60% of the region is suitable. By 2070, about 80% of the region becomes suitable under low emissions, compared to 55% under high emissions (Figure 11). By 2090, about 80% of the region remains suitable under low emissions, compared to 40% under high emissions.

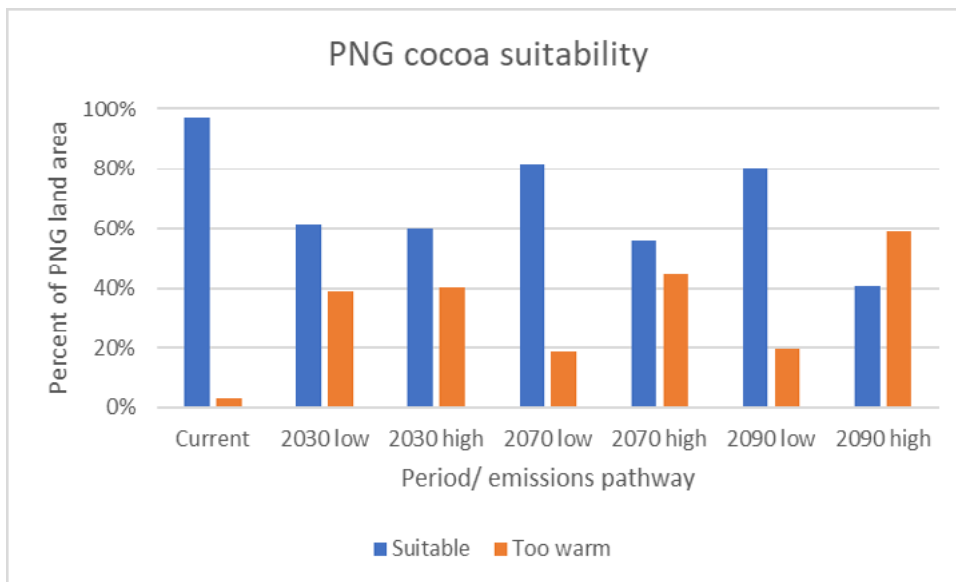


Figure 11 Suitability for cocoa growing (Percent of PNG land area). These calculations are drawn from the best case model (CNRM-CM5) with time periods and emissions pathways as indicated.

The Paris Agreement target of keeping global warming to well below 2°C above pre-industrial levels is consistent with the low emission scenario RCP2.6. For PNG, this is most closely reflected in the ‘best case’ scenario (Figure 8, top panel).



Cocoa pods on the tree © SPREP

4.3 Will projected average annual rainfall changes affect cocoa production?

Rainfall changes may increase the risk of diseases and pests. Increased pressure from Black Pod Disease (*Phytophthora palmivora*), while currently well controlled in PNG, is increased if rainfall is above 2500 mm per year (Figure 12).

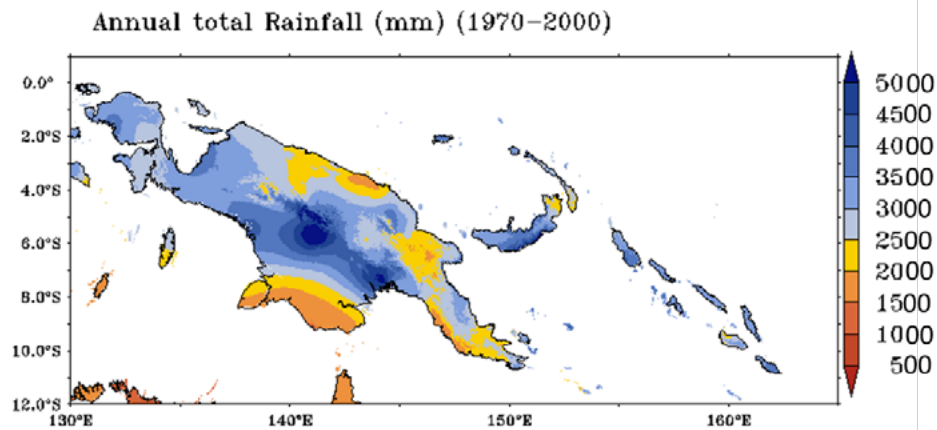


Figure 12 Annual rainfall PNG (mm) (1970-2000) (Source: WorldClim).

Average annual rainfall totals above 2500 mm are already experienced in many parts of PNG, so projected increased rainfall totals (Figure 13) means the industry must continue to manage fungal disease into the future, especially in wet years.

The long-term average annual rainfall is projected to increase in most areas of Papua New Guinea in almost all models (median change under low emissions scenarios of +4% by 2030, +4% by 2050, +5% by 2070) The increase is greater for the higher emissions scenarios, especially towards the end of the century (median change under high emissions of +10% by 2070; Figure 13) (CSIRO and SPREP, 2021).

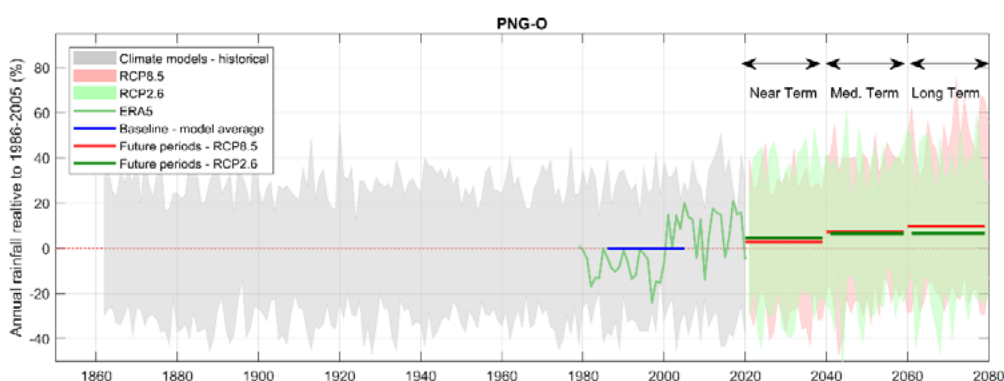


Figure 13 Average annual rainfall in the Papua New Guinea regions relative to 1850-1900 (%) in three gridded datasets using observations (coloured lines, as marked) and simulated in CMIP5 models, showing the range of all models for the past period (grey), the future under a high emissions pathway (pink band) and a low emissions pathway (green band). Thick lines show the mean of all models in 20-year periods: the baseline 1986-2005 (blue) and future 20-year periods centred on 2030, 2050 and 2070 (RCP8.5; red lines, RCP2.6; green lines) (CSIRO and SPREP, 2021).

Overall, average rainfall changes should not preclude production of cocoa in PNG. There will still be wet and dry years and decades due to natural variability. The effect of climate change on average rainfall may not be obvious in the short or medium term due to natural variability. Future rainfall variability will continue, with some periods showing wetting trends and other periods showing drying trends (Figure 14).

Box 3: How will future changes evolve?

As with the observed climate, there will be different ways the projected rainfall future could unfold (Figure 14). Two examples from separate climate model simulations are superimposed over historical and future simulations from multiple climate models for the PNG region. Natural climate variability will mean the change isn't steady or smooth – there may be wetting periods and drying – that is, short-term trends either up or down (CSIRO and SPREP, 2021).

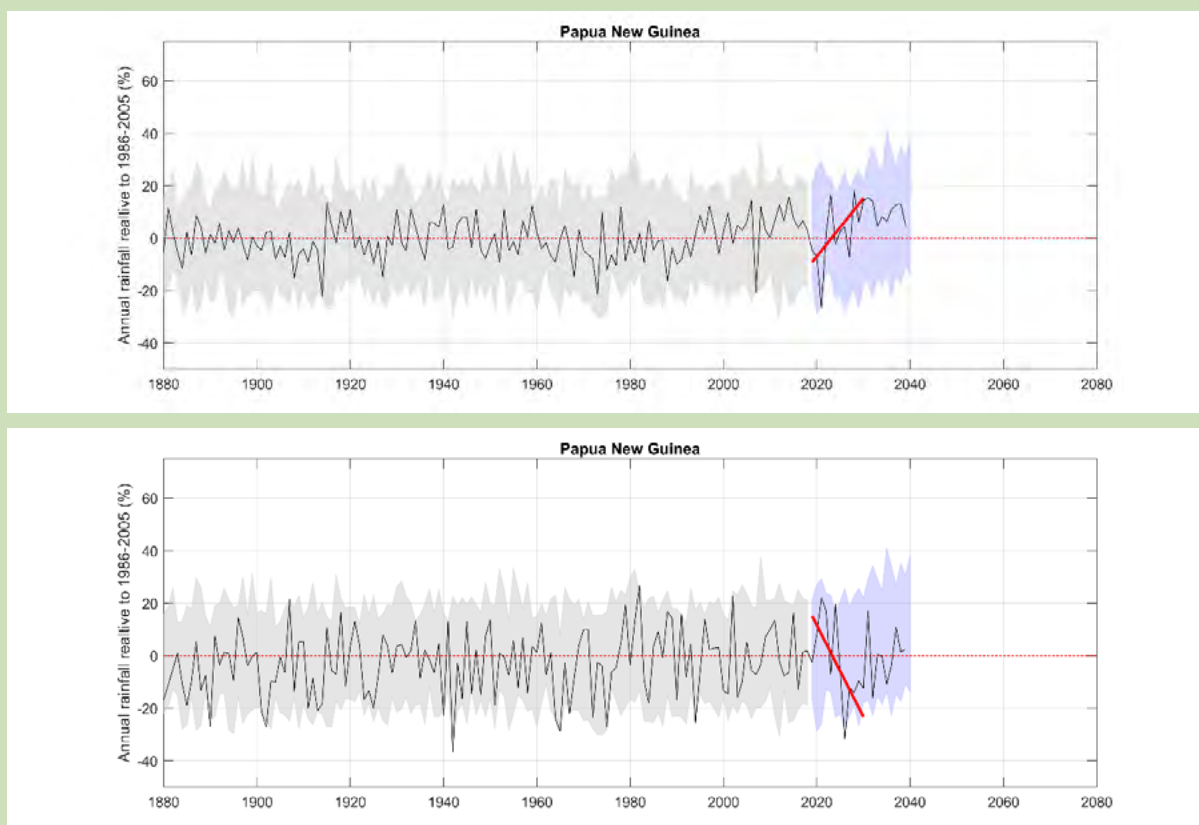


Figure 14 Average annual rainfall anomaly (cf. the recent 1986-2005 period) for the PNG (oceans) region for the historical period (1880-2020) (grey band) and the future (2020-2040) (blue band) based on 36 CMIP5 models. Separate climate model simulations indicate hypothetical rainfall time-series (black lines) with short-term trends indicated (red lines) (top and bottom frames) (CSIRO and SPREP, 2021).

4.4 How may extreme rainfall projections affect cocoa production?

Extreme rainfall can have implications for fungal disease as the higher moisture levels in the environment favour fungal growth. Extreme rainfall is also associated with flooding which can cause problems for drainage, soil erosion and accessibility to farms. This has been mentioned as a factor affecting cocoa growing in PNG.

There is high confidence that the frequency and intensity of extreme rainfall events will increase because a warmer atmosphere can hold more moisture (Field et al. 2012). Furthermore, increases in extreme rainfall in the Pacific are projected in all available climate models.

PACCSAP projections indicate that by 2030, the current 1-in-20-year event daily rainfall amount may increase by approximately 14 mm under RCP2.6 and 12 mm under RCP8.5. By 2090, it is projected to increase by approximately 21 mm for RCP2.6 and by 55 mm for RCP8.5. By 2090, the majority of models project the current 1-in-20-year event daily rainfall event will become, on average, a 1-in-7 year event for RCP2.6 and a 1-in-4 year event for RCP8.5 (Australian Bureau of Meteorology and CSIRO 2014).

NextGen analysis indicates that annual maximum daily rainfall is projected to increase in the future. Figure 15 shows observed annual maximum daily rainfall for 30 years centred on 2000 (i.e. 1984-2013) and projected annual maximum daily rainfall for 30 years centred on 2030 (2016-2045), 2050 (2036-2065) and 2070 (2056-2085) over Kavieng (New Ireland), Madang and Wewak (East-Sepik). Projections indicate under RCP8.5 (a 'worst case' scenario) that over Kavieng and Wewak (which are at approximately the same latitude), the median annual maximum daily rainfall for the 2030 (2016-2045) period is projected to increase by about 100 mm, however, for the periods after that the increases are not as large. Over Madang, the median annual daily maximum rainfall for the 2030 (2016-2045) period is projected to increase by about 50 mm, however, for the periods after that the projections do not show much change with respect to the 2030 period.

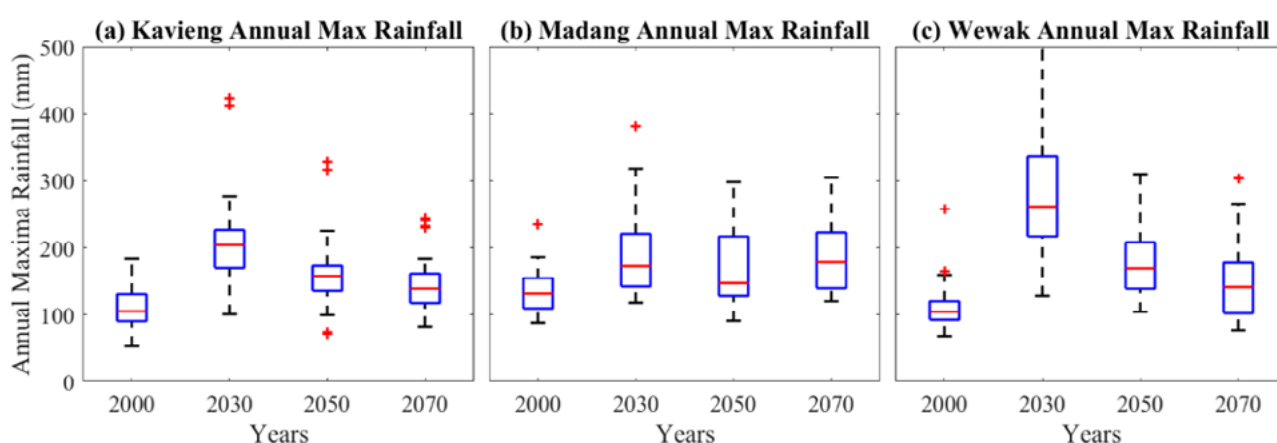


Figure 15 Boxplots of observed and projected annual maximum daily rainfall over Kavieng (New Ireland), Madang and Wewak (East-Sepik). Projections are made using the Hadley Centre Global Environment Model 2 - Earth System (HADGEM2-ES) under RCP8.5 with Quantile-Quantile bias correction based on weather station data (see Methods section).

These increases in extreme rainfall could aid crop production through recharging of dams and water-catchments. However, increasing risks from fungal growth, flooding, soil erosion, farm access and landslides would have a negative impact on crop production.

Rainfall projections have lower confidence compared to temperature projections, so changes outside the projected ranges are possible. This means that specific adaptation strategies need to be flexible together with ongoing monitoring and assessment of the issues.

4.5 How may drought conditions change under future climate projections?

Droughts associated with El Niño can have major impacts on agriculture. The 2015–16 drought reduced food security in PNG (Ilese et al, 2021). Drought and frost affected about 700,000 people and about 450,000 people faced critical food shortages, affecting peoples’ health, diet and access to water (Ilese et al., 2021).

Cocoa production is susceptible to long periods of drought which cause cocoa buds to wither, resulting in reduced yields (Taylor et al. 2016). Other reports suggest a dry season of more than three months with less than 100 mm rain per month can be detrimental to cocoa production (Wood and Lass 2008).

Future changes in rainfall variability for PNG are affected by the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Interdecadal Pacific Oscillation (IPO). An increase in strong El Niño and La Niña events is projected (Cai et al, 2014), along with more extreme positive phases of the IOD (Cai et al, 2018), but potential changes in the IPO are unknown (ESCC, 2020).

Drought projections are described in terms of changes in the proportion of time in drought, frequency and duration by 2090 for RCP8.5 (Figure 16). For Papua New Guinea, the overall proportion of time spent in drought is expected to decrease in most locations with the frequency, duration and intensity of drought in all categories projected to decrease. This would reduce risks for food security.

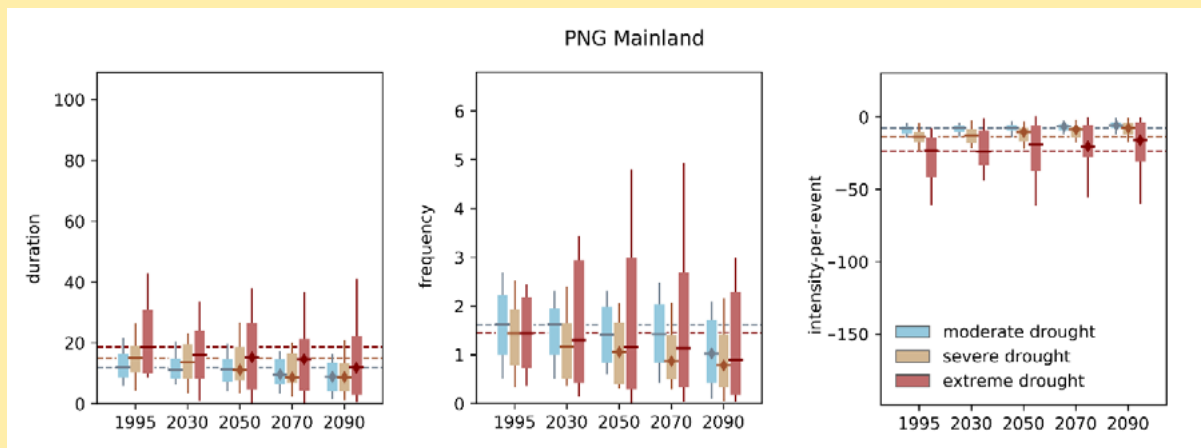


Figure 16 PNG mainland average of drought metrics (based on the Standardised Precipitation Index) for each drought category in the reference period (20 years centred on 1995) and future periods (20-years centred on 2030, 2050, 2070, 2090) (drought duration is in months, frequency is in “number of events per period”, while intensity is unitless). The 34-model ensemble is shown as median, 10th and 90th percentile (bars) and minimum and maximum values (whiskers). The dashed lines show the multi-model median for the baseline period for each drought category. The diamond symbols denote that the median metric at a given period in the future statistically differs (with $p < 0.05$) to the mean metrics in the reference period (1995). For drought intensity, the more negative the value, the more intense the event (Ilese et al. 2021).

5 Adaptation: Some preliminary notes

In any climate hazard-based impact assessment, designing helpful adaptation strategies is a critical step. This step involves consideration of the results from the physical assessments presented earlier in this report, combined with extensive engagement with cocoa farmers, other stakeholders and experts from the community.

Due to inability to travel and limited opportunity to meet with the community through preparation of this report due to the COVID 19 pandemic, this section on adaptation is not comprehensive. A few points are presented below to guide more in-depth discussions with key stakeholders to develop potential adaptation strategies for the cocoa industry.

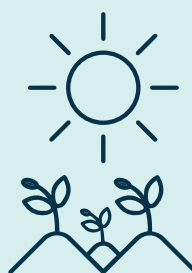
There are several ways in which cocoa producers can become more resilient to all of these challenges, including introduction of new farm management practices, farming in new areas, changing to more heat/disease-tolerant varieties, and diversifying the farming system to incorporate other crops or products. Further analysis of adaptation options can be found in *Vulnerability of Pacific Island agriculture and forestry to climate change* (Taylor et al. 2016).

Possible adaptation responses may therefore include:

- Identifying whether cocoa production in PNG could be expanded further up the adjacent slopes of the catchment to follow the change in the optimal temperature envelope. It is noted that companies are increasingly coming out with revised sustainability commitments that include a greater focus on environment sustainability, particularly on addressing deforestation and incorporating climate-smart objectives (Noponen et al. 2014).
- Changing the aspect for growing cocoa so as to avoid the harsh afternoon sun exposure, e.g. less west facing, as was found for grapevines in Australia (Webb et al. 2009).
- Introducing more shade trees to ensure 75 % shading is maintained.
- Investigating changes to the crop variety through selective breeding could develop higher temperature tolerance strains of cocoa for production in existing farm areas of PNG.



Identify whether cocoa production can be moved up the adjacent slopes



Less west facing slopes to avoid afternoon sun exposure



Maintain 75% shading



Selective breeding of climate tolerant cocoa variety

Cocoa nursery © Anonymous 2017

6 Conclusions and further research

Until 2030, the impact of increasing temperature on cocoa production is likely to be minimal - about 60% of the region remains suitable. By 2070, about 80% of the region becomes suitable under low emissions, compared to 55% under high emissions. By 2090, about 80% of the region remains suitable under low emissions, compared to 40% under high emissions.

Annual average rainfall is projected to increase 4% by 2030 and 4-7% by 2050. This may increase the incidence of Black Pod Disease in regions with above 2500 mm of rainfall per year. Therefore, the cocoa industry must continue to manage this disease into the future, especially in wet years.

The frequency and intensity of extreme daily rainfall events is projected to increase. By 2030, the annual maximum daily rainfall intensity increases 50 mm over Madang and 100 mm over Kavieng and Wewak. This could cause problems for drainage, soil erosion and accessibility to farms.

Drought frequency intensity and duration are projected to decrease. This would reduce risks for cocoa production.

Beyond 2030, under a high emissions pathway, cocoa-growing areas such as PNG and Solomon Islands are likely to be disadvantaged compared to other countries where temperatures are currently below optimal levels, such as Vanuatu, Samoa and Fiji (although these countries are affected by cyclones).

It would be interesting to understand the relative advantage of PNG as a cocoa producer compared to other countries also facing climate related threats, noting that cocoa is a viable and, in many cases, expanding industry sector in some countries, subject to various ambient climate conditions, both current and future.

Cocoa © Skia website <https://www.skia.ws/gallery/>



7 Methods detail

The methodological framework used in this assessment can be found in the NextGen guidance document Step-by-step: How to undertake a hazard-based climate change impact assessment (CSIRO and SPREP 2022).

NextGen time series data

Mean annual temperature data were taken from the observed datasets HadCRUT4 (1850 to 2019; Morice et al. 2012), NOAA GlobalTemp (1880 to 2019; Zhang et al. 2017), Cowtan and Way (1850 to 2019; Cowtan and Way 2014) and GISTEMP (1880 to 2019; Lenssen et al. 2019). Seasonal average rainfall data were taken from the observed datasets CMAP and GPCP (Xie and Arkin 1997, Adler et al. 2018). Mean annual temperature projections and mean seasonal rainfall projections were taken from up to 40 CMIP5 models for RCP8.5, RCP4.5 and RCP2.6.

Model and observed data were averaged over the Exclusive Economic Zone of PNG, including all land and surrounding oceans, and regions are defined in Australian Bureau of Meteorology and CSIRO (2014) (Figure 17). Change relative to 'early industrial' was calculated relative to 1850-1900, or else 1880-1900 if data were available. For this cocoa case study, the 'Oceans and islands' region was used.

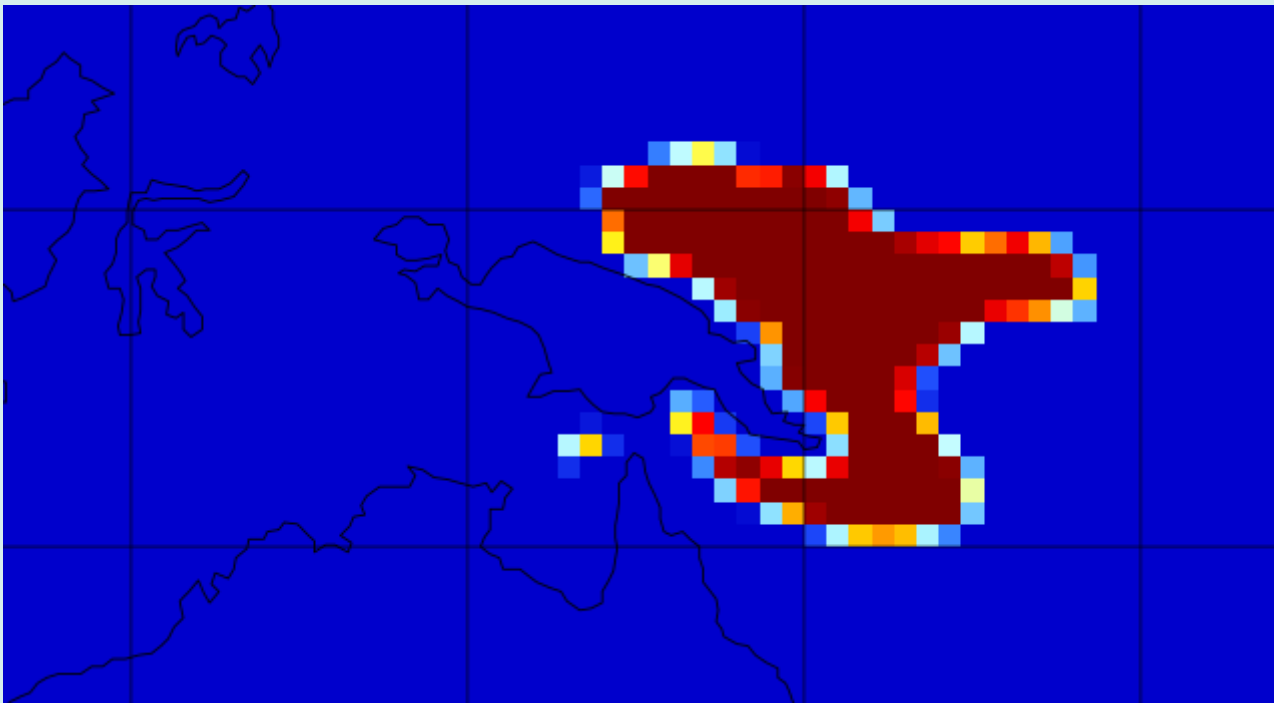


Figure 17 PNG region used for NextGen trend and projections analysis Oceans and Islands.

NextGen modelling reports results for CMIP5 global climate models (Taylor et al. 2012) are verified for use over the Pacific region (Grose et al. 2014). Trends over near-term periods were calculated using ordinary least squares linear fits. Change relative to 'early industrial' was calculated relative to 1850-1900, or else 1880-1900 if data were available (e.g. BOX 1 and BOX 2).

Climate projections

Future climate data were produced using the delta change methodology (CSIRO and BoM 2015), where projected change data from CMIP5 models that perform well in the Pacific region (Grose et al. 2014) are applied to the Worldclim historical climatology as described in Figure 18. ‘Best case’ and ‘worst case’ climate models were selected using Climate Futures to capture the range of temperature and rainfall projections for PNG (CSIRO and BoM 2015).

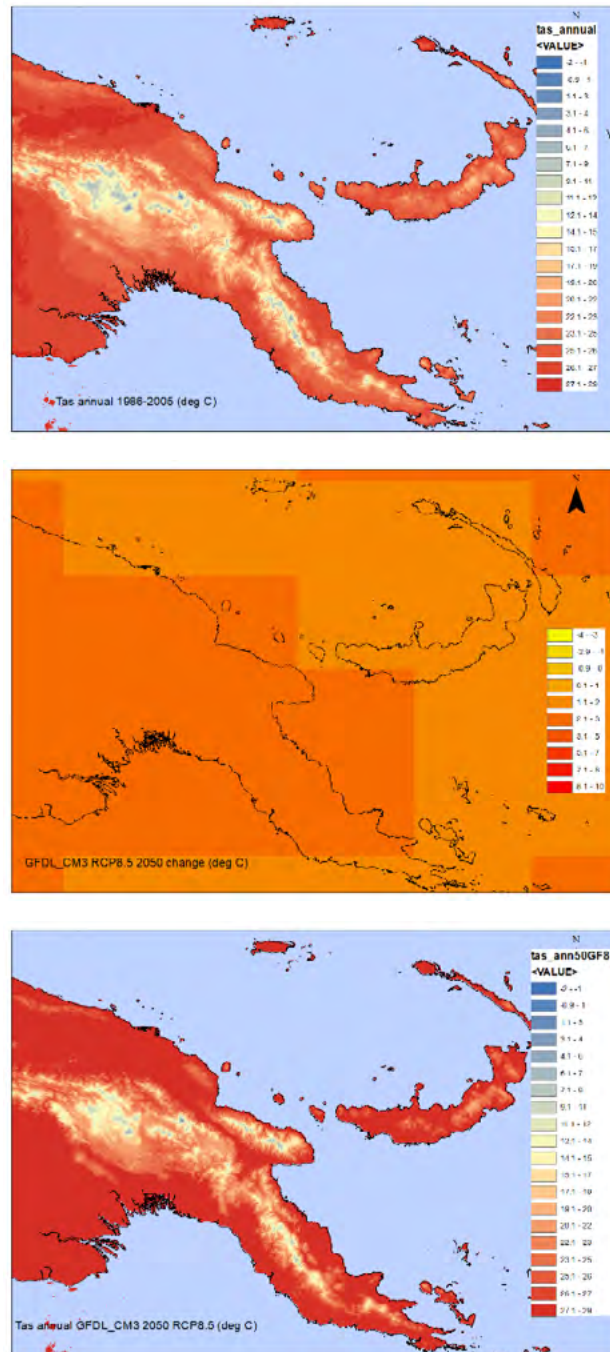


Figure 18 Delta change method for creating climate projections. Future annual mean temperature projection for 2050 (2036-2065) (GFDL-CM3 RCP8.5) (bottom) is created by adding projected temperature change (GFDL-CM3 RCP8.5 2050 (2036-2065) relative to 1995 (1981-2010) (middle) to the observed temperature data (Modified Worldclim 1981-2010; see below in Methods section) (top).

Modified Worldclim baseline dataset

High-resolution climate surfaces for each month have been derived from Worldclim (Version 2) (Fick and Hijmans 2017) at www.worldclim.org. Worldclim provides a globally consistent, high-resolution climate surface for temperature. The Worldclim baseline represents the 1970-2000 baseline period, i.e. 30 years centred on 1985. This baseline has been modified for our analysis to represent a 20 years centred on 1995 (1981-2010) baseline, consistent with the IPCC and PACCSAP. The following steps were followed to produce modified Worldclim data for use in this report:

1. Calculated average monthly global gridded temperature surfaces (CRU, GISS, Berkeley, NOAA, Cowtan-Way and JRA25anl) centred on 1970-2000 and 1981-2010 (for Cowtan and Way this was an anomaly dataset).
2. Calculated the differences in temperature across the two periods for each global gridded dataset.
3. Averaged the differences from all of the datasets.
4. Applied the average difference to the WorldClim 2.0 data for 1970-2000.

Extremes

For projections of annual maximum daily rainfall, the Hadley Centre Global Environment Model 2 - Earth System (HadGEM2-ES; Collins et al. 2011) outputs are used, obtained from the Infrastructure of the European Network for Earth System Modelling (IS-ENES) domain. HadGEM2 was found to be one of the few models with substantial ability to reproduce not only a realistic climatology of tropical cyclones (TCs) but also the ENSO-TC relationship in the Pacific (Chand et al. 2017).

A Quantile-Quantile (QQ) scaling technique has been utilised to bias correct the projections over Kavieng (New Ireland), Madang and Wewak (East-Sepik) using daily-rainfall observations (QQ: <https://www.climatechangeinaustralia.gov.au/en/obtain-data/application-ready-data/scaling-methods/>).



© Kristiana Pinne

8 References

- Adler, R. F., et al. (2018). The Global Precipitation Climatology Project (GPCP) monthly analysis (new version 2.3) and a review of 2017 global precipitation. *Atmosphere* 9(4): 138.
- Anonymous (2017). Cocoa Board of PNG (CBPNG) Special Report. Cocoa Board of Papua New Guinea, Kokopo, ENBP. <http://www.cocoaboard.org.pg/>.
- Australian Bureau of Meteorology and CSIRO (2011). Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview.
- Australian Bureau of Meteorology and CSIRO (2014). Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports., Pacific-Australia Climate Change Science and Adaptation Planning Program, Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia.
- Bisseleua, H. D. (2019). How Cocoa Agroforestry Systems Can Help Farmers in West Africa, World Cocoa Foundation.
- Bourke, R. M., et al. (1993). Mapping agricultural systems in Papua New Guinea. In Population, Family Health and Development. *Papers from 19th Waigani Seminar*. T. Taufa and C. Bass. University of Papua New Guinea, Port Moresby. Volume 1: 205-225.
- Bourke, R. M. and T. Harwood (2009). *Food and Agriculture in Papua New Guinea*, ANU E Press.
- Cai, W., et al. (2014). Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change* 4, pages 111–116
- Cai, W., et al. (2018). Stabilised frequency of extreme positive Indian Ocean Dipole under 1.5°C warming. *Nature Communications*, 9(1): 1-8.
- Collins, W., et al. (2011). “Development and evaluation of an Earth-System model–HadGEM2.” *Geosci. Model Dev. Discuss* 4(2): 997-1062.
- Cowtan, K. and R. G. Way (2014). “Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends.” *Quarterly Journal of the Royal Meteorological Society* 140(683): 1935-1944.
- CSIRO and BoM (2015). Climate Change in Australia Technical Report. M. Ekström, C. Gerbing, M. Grose et al. Melbourne, Australia, CSIRO Marine and Atmospheric Research and Bureau of Meteorology (CAWCR) and the Department of the Environment.
- Chand, S. S., et al. (2017). “Projected increase in El Niño-driven tropical cyclone frequency in the Pacific.” *Nature Climate Change* 7(2): 123-127.
- CSIRO, Australian Bureau of Meteorology and SPREP (2014). Climate in the Pacific: a regional summary of new science and management tools, Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program Summary Report. Melbourne, Australia, Commonwealth Scientific and Industrial Research Organisation.
- CSIRO and SPREP (2017). Developing Climate Change Information for the Pacific: Guidance Material to Raise Awareness and Facilitate Sectoral Decision-Making Using Science-Based Climate Change information and Services. Melbourne, Australia, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat for the Pacific Regional Environment Program (SPREP).
- CSIRO and SPREP (2021). Enhanced ‘NextGen’ Projections for the Western Tropical Pacific: Current and Future Climate for PNG. Final report to the Australia-Pacific Climate Partnership for the NextGen Climate Projections for the Western Tropical Pacific Project. Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat of the Pacific Regional Environment Programme (SPREP), CSIRO Technical Report, Melbourne, Australia.
- CSIRO and SPREP (2022). Step-by-step: How to undertake a hazard-based climate change impact assessment. A report to the Australia-Pacific Climate Partnership-funded Climate Projections for the western tropical Pacific (NextGen) project. Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat of the Pacific Regional Environment Programme (SPREP), CSIRO Technical Report, Melbourne, Australia.
- Curry, G., et al. (2009). “Social and economic impacts of Cocoa Pod Borer in East New Britain Province, Papua New Guinea.” *Strategies for Restoring Livelihoods. Research Unit for the Study of Societies in Change, Curtin University of Technology*.

- Curry, G. N., et al. (2015). "A bridge too far? The influence of socio-cultural values on the adaptation responses of smallholders to a devastating pest outbreak in cocoa." *Global Environmental Change* 35: 1-11.
- Dohmen, M. M., et al. (2018). *Climate Smart Agriculture in Cocoa*, World Cocoa Foundation.
- ESCC (2020). Scenario analysis of climate-related physical risk for buildings and infrastructure: climate science guidance. Technical report by the National Environmental Science Program (NESP) Earth Systems and Climate Change Science (ESCC) Hub for the Climate Measurement Standards Initiative.
- FAO (2019). "FAOSTAT." Retrieved 4/5/2020, 2020, from <http://www.fao.org/faostat/en/#data/QC>.
- Fick, S. E. and R. J. Hijmans (2017). "WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas." *International Journal of Climatology* 37(12): 4302-4315.
- Field, C. B., et al. (2012). "IPCC, 2012: Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change." *Cambridge University Press, Cambridge, UK, and New York, NY, USA* 30(11): 7575-7613.
- Grose, M. R., et al. (2014). "Assessment of the CMIP5 global climate model simulations of the western tropical Pacific climate system and comparison to CMIP3." *International Journal of Climatology* 34(12): 3382-3399.
- Hanson, L. W., et al. (1998). *Cocoa and coconut growing environments in Papua New Guinea*, Australian Agency for International Development.
- Ilese, V., et al. (2021). "Historical and future drought impacts in the Pacific islands and atolls." *Climatic Change* 166(1): 1-24.
- Läderach, P., et al. (2013). "Predicting the future climatic suitability for cocoa farming of the world's leading producer countries, Ghana and Côte d'Ivoire." *Climatic Change* 119(3): 841-854
- Lenssen, N. J., et al. (2019). "Improvements in the GISTEMP uncertainty model." *Journal of Geophysical Research: Atmospheres* 124(12): 6307-6326.
- McGree, S., Herold, N., Alexander, L., Schreider, S., Kuleshov, Y., Ene, E., Finaulahi, S., Inape, K., Mackenzie, B., Malala, H., Ngari, A., Prakash, B. and Tahani, L. (2019). Recent changes in mean and extreme temperature and precipitation in the western Pacific Islands. *Journal of Climate* 10.1175/JCLI-D-18-0748.1: JCLI-D-18-0748.0741.
- Morice, C. P., et al. (2012). "Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set." *Journal of Geophysical Research: Atmospheres* 117(D8).
- Nelson, P., et al. (2011). Nutritional status of cocoa in Papua New Guinea, Commonwealth of Australia.
- Noponen, M. R., et al. (2014). "3.3 A landscape approach to climate-smart agriculture in Ghana."
- Pearce, D. (2016). *Sustaining cocoa production: impact evaluation of cocoa projects in Indonesia and Papua New Guinea*. Canberra, Australia, ACIAR.
- Reynolds, O. L., et al. (2019). Basic research on the Cocoa Pod Borer in Papua New Guinea to permit effective pest management, ACIAR.
- Taylor, K. E., et al. (2012). "An overview of CMIP5 and the experiment design." *Bulletin of the American Meteorological Society* 93(4): 485-498.
- Taylor, M., et al. (2016). *Vulnerability of Pacific Island agriculture and forestry to climate change*, SPC.
- Van Vuuren, D. P., et al. (2011). "The representative concentration pathways: an overview." *Climatic Change* 109(1-2): 5-31.
- Webb, L., et al. (2009). "Extreme heat: managing grapevine response." *GWRDC and University of Melbourne: Melbourne*.
- Wood, G. A. R. and R. Lass (2008). *Cocoa*, John Wiley & Sons.
- Xie, P. and P. A. Arkin (1997). "Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs." *Bulletin of the American Meteorological Society* 78(11): 2539-2558.
- Zhang, H., et al. (2017). NOAA Global Surface Temperature Dataset (NOAAGlobalTemp), Version 5.0. NOAA National Centers for Environmental Information.

9 Appendix

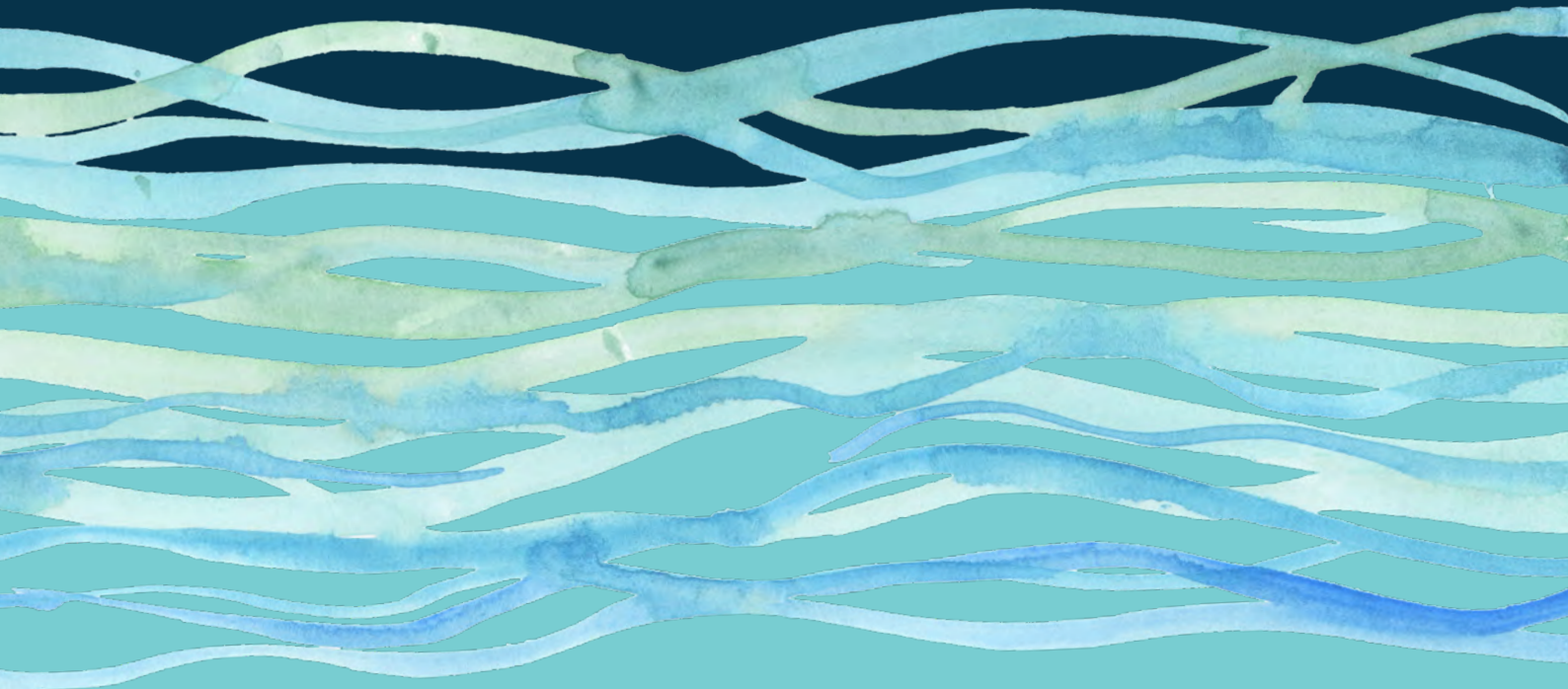
List of Workshop Attendees

Pacific Next Generation Climate Projections

Date: December 2020

Location: Port Moresby

Attendees	Organisation
A/g Managing Director, Jacob Ekinye	Climate Change and Development Authority, PNG
Tom Kukhang	Coffee Industry Corporation, PNG
Chris Fidelis	Tavilo Cocoa Research Centre, Cocoa Board of PNG
Kasis Inape	National Weather Service, PNG
Kisolei Lina	National Weather Service, PNG
Kila Kila	National Weather Service, PNG
Allan Tobalbal Oliver	The World Bank, PNG
Adnan Falak	Market Development Facility, Pakistan
Nige Kaupa	Australian High Commission, Port Moresby
Nicholas Saunders	Australian High Commission, Port Moresby
Tanuvasa Semy Siakimotu	PHAMA+ Program, Australia
Dr John Moxon	Cocoa Board of Papua New Guinea
Potaisa Hombunaka	Coffee Industry Corporation, PNG
Bill Humphrey	Coffee Industry Corporation, PNG
Clement Kunandi Victor	Department of Agriculture and Livestock, PNG
Leanne Webb	CSIRO, Australia
Dewi Kirono	CSIRO, Australia
Johanna Johnson	Australia Pacific Climate Partnership, Australia
Gillian Starling	Australia Pacific Climate Partnership, Australia
Katie Frisch	Australia Pacific Climate Partnership, Australia
Hannah Barrowman	Australia Pacific Climate Partnership, Australia



www.rccap.org

www.pacificmet.net

www.pacificclimatechange.net

