

The Effects of Climate Change on Animal Production in Fiji

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Abstract

Climate change is a great impact on Fiji's ecosystem including animal (livestock and marine) and crop production from past decades and still possesses a large effect on their economy as well. These climatic events include flooding, rise in ambient temperature, rise in the sea level, droughts, tropical cyclones, and all others that bring large changes to the environmental system. These large changes adversely affect animal production and its economy in Fiji. Not only this, individuals that are linked to animal production are also affected through climatic conditions such as loss of income and livestock species that die out during cyclones and other aspects. Not only the terrestrial species but the marine organisms are also affected since climatic changes bring alterations to their feeding period and the mating time leading to a vast decrease in organisms' health, quality, and population. Consequently, the Fijian government and other Pacific organizations have brought strategies like adaptation plans to implement in animal production sectors. These plans and methods will help farmers in stimulating their farming systems and adapting to climatic changes and hence, this will lead to increased productivity and economy. The aim and objective of this review are to define and elaborate the climatic change effects on livestock and marine production in Fiji and effective solutions adapted by Fiji and other Pacific governments to refrain from adverse climate conditions.

Keywords: climatic events, Fijian government, adaptation

1. Introduction

Fiji is regarded as one of the South Pacific Island Countries (SPICs) whereby, they are geographically segregated into Micronesia, Melanesia, and Polynesia. Almost every livelihood in Fiji relies on agriculture, fishing, and livestock production for their living and income (Reddy, 2007; FAO, 2008). However, their livelihoods have been endangered by climate change over many years, resulting in poor progress in their living style and income, thus, and increasing poverty in Fiji. Numerous studies in Fiji have pointed to global warming that has been associated with enhanced effects of greenhouse gases, such as, carbon dioxide, nitrous oxide, methane, ozone, and an increase in water vapor (Ramanathan & Feng, 2009; Montzka et al., 2011). The animal species in Fiji experience many climatic threats such as temperature changes and heat stress which eventually affects the fertility rate of male and female livestock (Igbal, 2022). The conservative threats imposed by climatic changes are staggering, however, if animal behaviorists each pick a central climate issue applicable to their ordered and habitat research interests, then interesting data and questions will arise that will be critical to conservational decision making (Buchholz et al., 2019). For instance, in the next 80 years or so, the sea level may rise by 0.53-0.98 m which will lead to beach-nesting species (plovers, sea turtles, horseshoe crabs) eventually losing their habitats (IPCC, 2014).

According to IPCC (2014), "while there is an ongoing argument around human responsibility for recent global warming, there is overwhelming evidence that humans are responsible for record carbon dioxide levels in the atmosphere". High-temperature levels have been recorded in different parts of the Pacific countries evidencing the high concentration of greenhouse gases are correlated to an increase in extreme temperatures in the atmosphere (Timmermann et al., 1999), and eventually the temperature level has been assumed to increase even more in the upcoming decades (Fischer & Schär, 2010). According to Pritchard et al. (2012), the process of increased high temperature and heat have led to ice melting in Antarctic and Arctic regions, that is; Antarctic

iceshelf thinning of up to 7 m per year. The thinning happens due to wind-driven movements of water that are warm, over deep canals crossing the continental shelf, thus, contributing to a rise in the sea level which gradually boosts the vulnerability of people and animals living in low lying areas to flood.

These climatic changes have been occurring for decades and will continue to occur until corrective measures have been found since livestock and marine species are losing their habitat and a time will come when these species go extinct due to rapid changes in the climatic conditions (Taylor & Kumar, 2016). Some of the island species are limited to adapt to climatic changes due to limited variation in their genes, small population, and smaller geographic ranges, thus, an increase in the climatic changes can gradually destroy these kinds of species leading to their extinction, (Jupitor et al., 2014). This leads to a vast decrease in animal production which later reduces the economic growth in Fiji. A National Development Plan was conducted in Fiji for performing actions that will reduce the effects of climate change and will increase the GDP [Gross Domestic Product] of the country. The National Development Plan, prepared by the Fijian Government, was to act upon the climatic changes and other factors (such as low exports and investments) to overcome these situations (climate change) and double the GDP of the country by 2036. The main objectives of this plan regarding agricultural sector involves; doubling the income (per capita) of the country, promoting food security, conserving our natural environment, and enhancing national security. However, the climatic changes, being unpredictable, performs as a major hindrance to the accomplishment of these objectives. For instance, TC Winston that occurred in 2016 caused major damages to Fiji's total GDP, accounting for a loss of 20%. Extreme changes like this (Tropical cyclone) can affect the options and outcomes of the development plan conducted (Government of Fiji, World Bank, and Global Facility for Disaster Reduction and Recovery, 2017). The Climate Vulnerability Assessment Report was organized with the objective to provide a better understanding on the natural hazard and climatic change threats that prohibits the development plans and objectives of the country.

2. How Does Climate Change Affect Animal Production?

Fiji's Senior Agriculture Officer of Animal Health and Production indicated that the agricultural sector performs a major role in the development of Fiji's economy by contributing around 15% to the total GDP, from which 5% comes from livestock production. This livestock sector involves essentialities for food security, economic development, and employment creation, thus, leading to higher foreign exchange earnings. However, due to changes in the climatic conditions, Fiji has been experiencing many fluctuations in the livestock industry, such as breed and milk production (SPC, 2011). As of last year (2021), the total GDP derived from the agricultural sector in Fiji is 10.4% which clearly depicts the adverse effects of climate change leading to lower agricultural production and economy (Fiji-Country Commercial Guide, Agriculture Sector, 2021).

According to Mary et al. (2016), "The threats to agricultural production from climate change arise largely from changes in temperature and precipitation and intensity of extreme weather events. These extreme events are likely to be more damaging, especially if their timing coincides with a crucial developmental stage in the life cycle of a living organism". [Climate change extortions to agricultural (crop and livestock sector) and fisheries production occur vastly from both temperature and precipitation alterations, as well as extreme weather change events. These extreme weather conditions can be more devastating if they will coincide their time of occurrence with the critical stages of development in the life cycle of an organism], like livestock species. Thus, making it hard for the animal species to recover from these kinds of adverse effects, as well as sometimes, the effect recovery is so difficult that species are not able to adapt, and another wave of extreme weather conditions occur again leading to more devastation and extinction of animal species]. A model was used by Pacific organizations namely Climate Model Intercomparison Project 3 (CMIP 3) to interpret the future consequences of extreme climatic changes, that is, rise in sea level, temperature change and many more. The table below (Table 1) shows the observed and predicted climatic changes in the Pacific regime including Fiji.

Table 1. Observed and projected summary of climatic changes in Pacific Island Countries

Climate Variable	RCP	Observed	2030	2050	2090
Air Temperature	RCP2.6		0.75 °C	0.75 °C	0.75 °C
	RCP4.5	Significant warming	0.75 °C	1.0 °C	1.5 °C
	RCP6.0	0.18 °C/decade, 1961-2011	0.75 °C	1.0 °C	2.2 °C
	RCP8.5		0.75 °C	1.5 °C	3.0 °C
Temperature Extremes		4-fold increase in the frequency of warm days and nights and decrease in cool days and nights, 1951-2011	Becoming more frequent and intense through 21st century and higher emissions scenarios	1 in 20-year extreme daily temperature will be 2-4 °C warmer than present extremes RCP8.5	
Rainfall	RCP2.6		Becoming wetter across much of region especially near-equatorial Kiribati and Nauru with a magnitude of change increasing through 21st century and higher emissions scenarios.		
	RCP4.5	No significant change-still dominated by natural variability	Drier French Polynesia and Pitcairn Islands.		
	RCP6.0				
	RCP8.5				
Rainfall Extremes		No significant change-still dominated by natural variability	Becoming more frequent and intense through 21st century and higher emissions scenarios	1 in 20-year extreme daily rainfall will occur every 7-10 years (RCP2.6) or every 4-6 years (RCP8.5)	
Sea-Level	RCP2.6			24 cm	40 cm
	RCP4.5	Significant global +19 cm rise since early 20th century		26 cm	47 cm
	RCP6.0			25 cm	48 cm
	RCP8.5			30 cm	63 cm
Tropical Cyclones		No significant change	Similar number or fewer tropical cyclones but those that occur will be more intense		
ENSO Events		No significant change but central Pacific ENSOs more frequent than eastern Pacific ENSOs	A continued source of inter-annual variability; associated rainfall extremes intensify and extreme El Niños (e.g., 1982-83, 1997-98) double in frequency during the 21st century		

Source: Vulnerability of Pacific Island agriculture and forestry to climate change (SPC, 2016).

2.1 Climate Change vs. Livestock Production and Productivity

Below are some of the impacts of climate change that affects livestock production in Fiji and other Pacific countries.

2.1.1 Effects of Changes in the Temperature

Livestock can usually adapt to small temperature increments. However, too much heat stress can affect livestock physiology, decreasing the fertility of males and females, and boosting the mortality rates. Many livestock species will gradually die if the temperature increases more than 42 to 45 °C. Specifically, poultry species are more prone to high vulnerability if there has been an increase in the temperature level, mostly when there is high humidity. Animals' appetite and feed intake are also reduced when the temperature rises above 30 °C. Local breeds in Fiji are highly adapted to such temperature levels; however, new animals that have been introduced to the environment get more affected by high temperature and relative humidity (King et al., 2006).

According to Christensen et al. (2004) and Morgan et al. (2007), it is being expected that high temperatures will result in plant tissue lignification's and thus, declining pastoral quality whereby, which will decrease their forage digestibility. There is a capability that climate change may cause amendments of C3 grasses to C4 grasses. These C3 and C4 plants that animals eat have a vast difference, such as C4 plants obtain a low quality of dry matter in larger amounts and possess increased carbon-nitrogen nutrition, whereas, C3 plants have less production yet they generally have more nutritional value (Easterling et al., 2007; Tubiello et al., 2007).

Van Dijk et al. (2010) found that climate change could also influence the disease trends in the future for livestock production. Incidents have been already recorded in Vanuatu, whereby, cattle are having intestinal problems (worms and infections) and the same has happened with piggery growers. These alterations in the patterns of disease occurrence depict a highly effective method to control the spread of extreme events like this (FAO, 2008). The following Figure 1 is used as an example to show an extreme increase in the temperature levels in Vanuatu which will eventually lead to changes in disease trend occurrence in the future ahead.

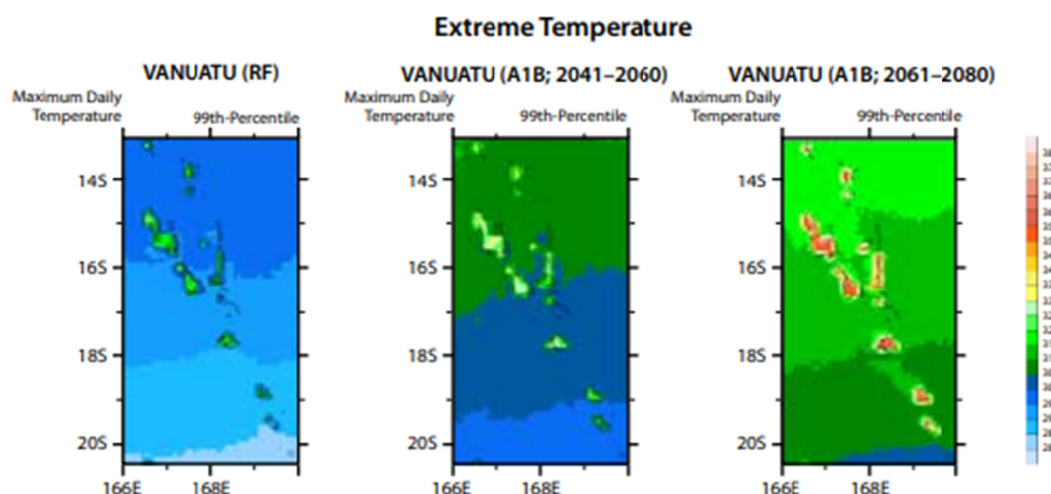


Figure 1. Extreme temperature projections conducted in Vanuatu

Source: The economics of climate change in the Pacific (Asian Development Bank, 2013).

Not only this, but Forage also provides 0-80% water content for livestock use, depending on the weather conditions. As the temperature level increases, the water demand also increases. For instance, *Bos taurus* water intake is 8 kg/kg of dry matter at 30 °C compared with 35 °C at 14 kg/kg dry matter (Thornton et al., 2009).

The Table 2 below shows the water intake of *Bos indicus* which is relatively very similar to *Bos taurus* breeds of water intake.

Table 2. *Bos indicus* water intake per kg of dry matter (DM) at three different temperature levels

	kg water intake/kg DM intake at 10 °C	kg water intake/kg DM intake at 30 °C	kg water intake/kg DM intake at 35 °C
Bos indicus breeds	3	5	10
Bos taurus breeds	3	8	14

Source: Vulnerability of Pacific Island Agriculture and Forestry to climate change (SPC, 2016).

2.1.2 Effects of Precipitation Changes

The IPCC reports in 2013 have indicated that there won't be any uniformity in regard to changes in the water cycle period and global warming. It has been projected that there will be small effects of warming on the average rainfall by the year 2030; however, the warming patterns will emerge after 2030, which will be much stronger for higher emission appearances. The reports have also illustrated the continued domination of El Niño-Southern Oscillation (ENSO) on annual variability in the tropical regions of the Pacific including Fiji, and due to an upraise of moisture availability, the precipitations related to ENSO events will intensify (IPCC, 2013).

Precipitation changes lead to drought weather conditions which can affect the livestock production in both direct and indirect ways, which is direct-less availability of water, and indirectly-pasture quality and quantity. Both effects can cause lower fertility rates and can also increase livestock vulnerability to diseases, thus, leading to a higher mortality rate (Thornton et al., 2009).

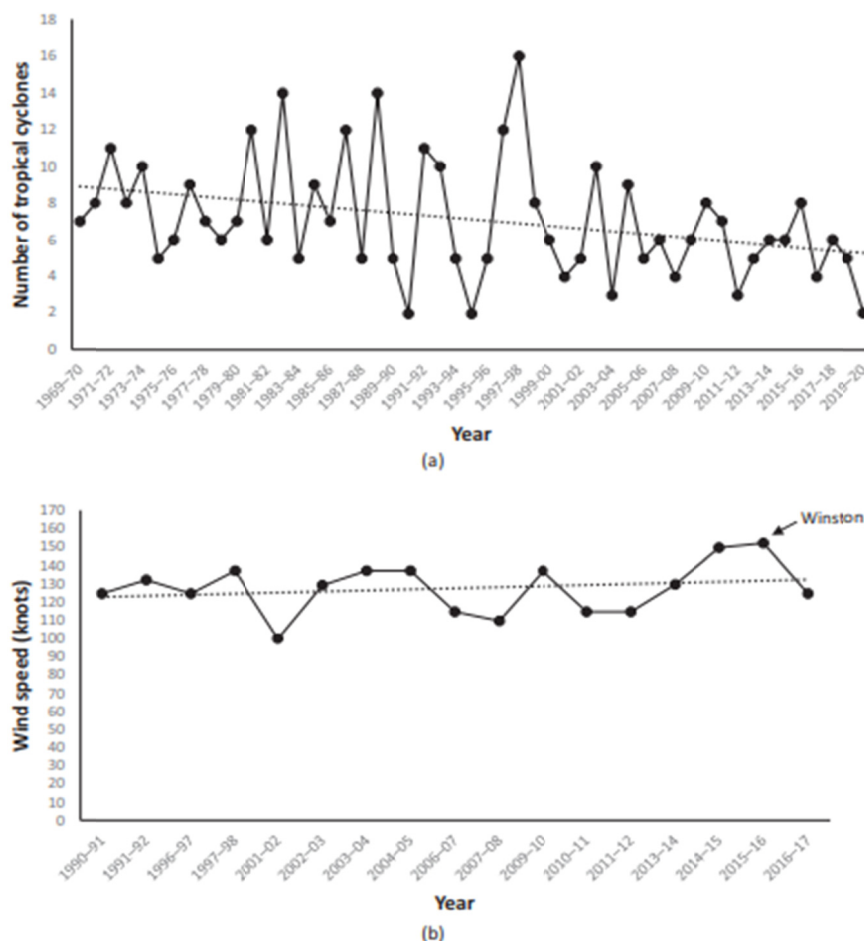
2.1.3 Effects of Variations in Rainfall Patterns

According to Thornton et al. (2009), "Increased rainfall can have a deleterious effect on livestock through the effects of muddy enclosures and fields on animal mobility; the promotion of waterborne diseases, hoof rot and pests (e.g., armyworm); and the reduction in feed availability and quality through the flooding of pastures and the spoilage of stored feed" [Variations in the rainfall patterns can have a devastating impact on livestock production such as, effects on field's animal mobility through muddy enclosures, more rapid spread of waterborne diseases and pests (worms), and high decline in the availability of feed products through flooding which causes wastage of feed that are stored]. Not only this, road access, machines and farm structures are also widely affected by high rainfall which leads to flooding. Uncooperatively, if there is a reduced amount of annual rainfall, then it can vastly decline the quality and quantity of stocked drinking water plus the feed. In areas where

the growing season length is shortened due to rainfall distribution changes, many animal species can suffer an extended period of water and nutritional stress. Thus, animals will have to search for feed and adapt to fewer water frequencies (Thornton et al., 2009). As the rainfall patterns change frequently or become more variable, the plant tissues lignify increasingly, possess declined digestibility (Giridhar et al., 2015), and alterations in the food composition towards less palatable species (da Silveira Pontes et al., 2015). These changes can cause shifts in land use that can comprise unfavorable animal forage compositions, enhancing difficulties for smallholders to control and manage deficits in the animal feeds during dry season. The variations in rainfall patterns also lead to the death of the livestock species (Thornton et al., 2014).

2.1.4 Effects of Extreme Events (Tropical Cyclone)

“Cyclones, droughts, floods, heat waves and other extreme events such as tsunamis and storm surges can lead to reduced production, injury and the death of livestock” (Hoberg et al., 2008). [Over the past years, many livestock farmers have observed numerous effects of cyclones, heat waves, droughts, storm surges and flooding which has caused a wide reduction in their livestock production through injury or even death of livestock during flooding, drought, and cyclone periods]. Hoberg et al. (2008) also mentioned that “the effects can be either direct, such as damage caused by falling trees and moving debris or through the drowning of animals in flooded areas, or indirect through impacts on feed and water quality and quantity” [these effects are caused either by direct damages like moving debris and falling of trees or drowning of livestock animals in areas where flooding occurs rapidly or through indirect effects on the quality of water and feed]. “Flooding can impede access to available pasture and if it persists, will eventually damage or kill inundated pasture. High winds and flooding can also damage management infrastructure such as roads, fencing, wells, feeding stalls, etc. which can all have a detrimental effect on livestock production” (Hoberg et al., 2008). [In terms of flooding, it can rapidly reduce the access of pasture availability and if this scenario will persist, then flooding can even kill deluged pastures. High winds during cyclones and flooding can also damage infrastructural management like fences, roads, feeding stalls and so on, which eventually can have harmful effects on livestock production and productivity as well]. Flood occurrence can also lead to waterborne disease not only in livestock but also in humans as well (Hoberg et al., 2008). Graphs 1a and 1b below shows the number of Tropical Cyclone and wind speed that happened in the most intense tropical cyclones received in the Pacific regime. The data was obtained from the Fiji Meteorological Service Office in 2020.



Graph 1. (a) Number of Tropical Cyclones and (b) wind speeds that occurred during intense cyclones in the portrayed years

Source: Impact of climate change on sustainable livestock production and existence of wildlife and marine species in the South Pacific Island Countries (Bakare et al., 2020).

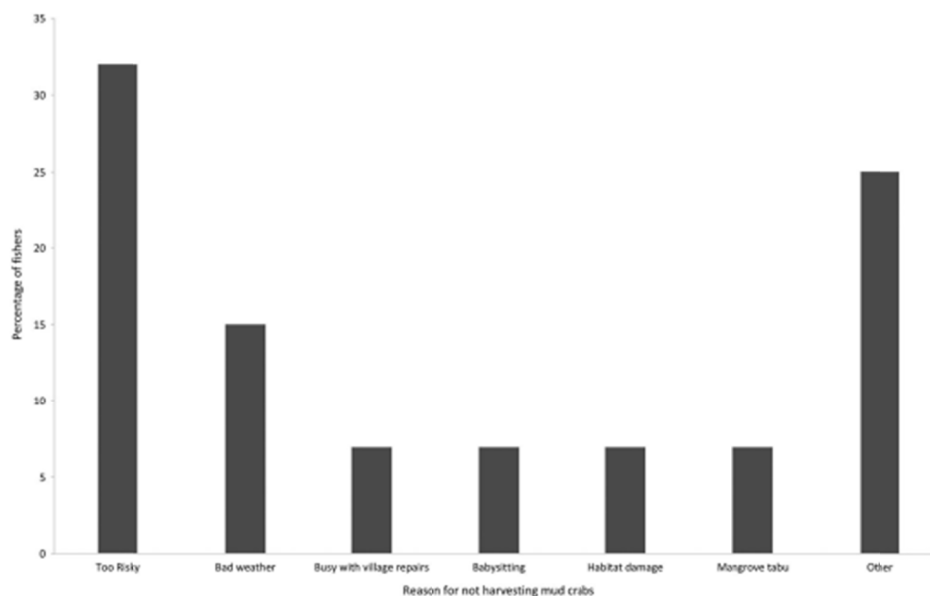
2.2 Effects of Climate Change on Milk Production

In Fiji, the composition of milk consumption was about 74,430,000 liter’s annually, yet only 16 percent was met by local production in terms of demand by consumers. As of the data collected in 2020 (Knoema, World Data Atlas, Fiji-Production of Milk, 2020), the milk produced by the dairy sector accounted for 12,393,000 liters. Fiji’s milk production has been declining year by year due to extreme climatic changes. Thus, farmers face various difficulties such as low quality and quantity of pasture, increased feed costs, low prices on milk, higher mortality rate, irregularity in farm services, increased milk spoilage, and problems associated with the land tenure department. Lakhan (2011) wrote “The cost of molasses has increased 58% in the past year. The cost of producing butter has increased 60% in the past 2 years, white life 17% and blue life 33%. While there have been increases in wholesale prices, suppliers are still paid \$0.55/liter since 2006”. [According to the records and observations that were done in Fiji, the molasses costs have boosted 58% from past years; butter production has increased by 60%, blue life by 33% and white life by 17% respectively. Even though the wholesale prices have upraised but the farmers and suppliers pay to remain the same from 2006, that is, \$0.55/liter]. There has not been a specific data regarding the amount paid to the dairy suppliers, however, the CEO of Fiji Cooperative Dairy Company Limited (FCDCL), Mr Sachida Nand), mentioned in 2014 about an increase in the pay (\$1.00/liter) for the farmers (The Fijian Government, 2014). Similarly, Mr. Ritesh Dass (Permanent Secretary-Ministry of Agriculture) also mentioned of increasing the income of dairy and other agricultural farmers (The Fijian Government, 2021). During summertime, milk production is the lowest and is more susceptible to changes in rainfall, temperature, flood, and hurricane threats. If the ambient temperature increases by even one degree, the

production level will rapidly decrease by 2%. Thus, these events if happening for longer periods can gradually decrease milk quality and quantity in the upcoming years (Lakhan, 2011).

2.3 Effects of Climate Change on Marine Sector

“Climate change has caused an intensity of extreme weather events” (IPCC, 2013), “which can result in significant and long-lasting effects to ecosystems” (Easterling et al., 2000) and the human communities that depend upon them. [The occurrence of different climatic conditions has caused extreme changes in weather events (IPCC, 2013), which has eventually resulted in long-lasting losses and effects on both terrestrial and marine lives (Easterling et al., 2000) and humans that depend upon these lives for their consumption and income]. A thorough survey was carried out by Thomas, Mangubhai, Vandervord, Fox, and Nand (2018) in Vanua Levu (Bua Province), Fiji, after the destruction made by Cyclone Winston. The surveyors interviewed all the fishers of mud crabs in Vanua Levu. Upon interviewing after 2-3 months of Tropical Cyclone Winston, the interviewers confirmed that they have stopped collecting/harvesting mud crabs in their area. The reason is, the Tropical Cyclone has damaged many trees, that is, fallen trees or debris stopping clear access to mangroves and secondly, bad weather. Not only this, but the cyclone has also led to higher destruction of crab habitats which eventually resulted in doing mangrove tabu (temporary no-take area). Some other reasons include village repairs due to the cyclone, babysitting and others. Thus, this depicts how extreme weather conditions can lead to such damages in marine life and later result in the extinction of such kinds of species (Thomas et al., 2018). Graph 2 below shows the survey results carried out in Vanua Levu.



Graph 2. Survey on the reasons that fishers do not collect mud crabs in Vanua Levu

Source: Impact of tropical cyclone Winston on women mud crab fishers in Fiji, 2018 (Thomas et al., 2018).

Effects of climate change have various uncertainties on the species of fish and artisanal fisheries. Many livelihoods in Fiji considerably depend on artisanal fisheries for their food and income. It is essential to know that reef and mangrove degradation can cause an increase in the variability of temporal and spatial fish abundance. The degradation is caused by climatic changes leading to turbidity, changes in water temperature and salinity as well. The increase of variability can eventually affect nutrition's in the fish species, thus, influencing the coastal incomes of which many people rely on for their feeding (SPC, 2006).

3. What Are the Effects of Climate Change on Livestock Pest and Diseases?

The climatic changes not only affect livestock production, but also the seasonal and geographical segregation of numerous pests and diseases through which in turn, affects their propagation, cycle, and infection periods, thus, livestock farmers find it difficult to identify the occurrence and control methods of such pest and diseases. Intermediate hosts, vectors and pathogens can either be directly or indirectly affected by climatic changes, such as, directly—temperature and humidity and indirectly—effects on interacting factors through weather change.

These events involve habitation changes like land use and cover, animal population movements, changes in the practices of management, as well as trade (Pilling & Hoffmann, 2011).

For instance, Mastitis disease in Fiji which highly affects cattle's milk glands, can change its occurrence and infection periods due to climatic changes. According to Balsom (2010), and Igbal (2021), climate can have a direct and indirect influence on mastitis onset. One of the ways climates have an indirect influence on mastitis is that during the wet season, the outside conditions are muddy, therefore, can cause an increase in the number of mastitis causing bacteria. As for housing, it influences the chance of getting mastitis, for example, when cattles are outdoor, they have higher chances of getting mastitis whereas, indoor housing can also trigger mastitis when the stalls are small, the cows can get injured and contain mastitis". Moreover, interpretations made on observed changes of future disease distribution trends have yet not been completely understood by experts. With the above-described climatic changes, the pathogens and hosts can be placed together in a new area, thus, deriving new disease and pest threats to animal health and livestock production (Pilling & Hoffmann, 2011).

Pathogens that spend half of their life cycle outside the animal host has a high chance of increasing their population due to a rise in the temperature level. Likewise, precipitation and moisture increase in the atmosphere can also lead to better survival for some pathogens, thus, boosting the chances of re-infections in animals which will gradually reduce the production level as well (Harvell et al., 2002). The table below shows the review done by Harvell et al. (2002) on the pathogen's rapid growth.

Table 3. Rapid development of pathogens due to climate changes on terrestrial animals and marine organisms

Host	Pathogen Type	Pathogen	Vector, reservoir, or intermediate host	Mechanism
1. Terrestrial Animals				
Domestic livestock, wild vertebrates	Nematode	Many directly transmitted nematodes	None	Faster larval development
Hawaiian forest birds	Protozoan	Avian malaria (<i>Plasmodium relictum</i>)	<i>Culex</i> mosquito	Faster development within mosquito
Domestic livestock and wild ungulates	Viruses	African horse sickness virus, Bluetongue virus (<i>Orbivirus</i> spp.)	<i>Culicoides</i> midges	Faster development in vector
Birds, humans	Viruses	Western equine Encephalitis (<i>Alphavirus</i> spp.) St. Louis encephalitis (<i>Flavivirus</i> spp.)	<i>Culex</i> mosquito	Faster development in vector
2. Marine Plant and Animal				
Coral	Fungus	<i>Aspergillus sydowii</i>	None	Faster growth
<i>Oculina patagonica</i>	Bacterium	<i>Vibrio shiloi</i>	None	Faster growth, Increased adhesion success
<i>Pseudopterogorgia americana</i> and <i>P. acerosa</i>	Fungus/ cyanobacterium	BlackBand Disease	None	Faster growth

Source: Climate warming and disease risks for terrestrial and marine biota (Harvell et al., 2002).

Similarly, Wittman and Baylis (2000) have found that insect vectors abilities changes with the variations in the temperature, such as: flies, ticks, and midges. An increase in temperature level has indicated that it can up-rise the frequency of the insect feeding system, which in return will increase disease transmissions and thus, again affect animal production and productivity level.

Climate change can also affect disease transmissions indirectly by influencing international livestock trade and transportation patterns, intensity, and farm area of animal production. For Instance, alterations in agricultural practices and land use due to climatic changes like drought and flooding will force humans and animals to migrate to new environmental areas, and hence, this will expose them to new pathogens and disease vectors, which will, later, infect the livelihoods (Thornton et al., 2009).

4. How Does Climate Change Affect Animals Feeding and Growth?

4.1 Livestock Feed Resources

Feed resource availability for livestock is significantly affected by climatic changes in Fiji and other Pacific Countries. The livestock species in Fiji highly contribute to the income and food security of several livelihoods (FAO, 2008). Natural pastures are mainly used for the diets of ruminant animals, while whole grain forms the

major ingredient in the diets of non-ruminant animals. Changing weather conditions such as droughts can severely affect the growth rates of many plant species that are used for feeding by defoliating (James, 2008). The table below was developed to show and predict the loss of endemic and indigenous plant species (land areas occupied by these plant species) that have been used for feeding in Melanesian (*e.g.*, Solomon Islands, Fiji, Papua New Guinea) countries. These plant species have been declining due to climatic changes happening in our environment.

Table 4. Estimates of Land Area occupied by vegetation types, predicted land area loss by 2100, endemic species percentage (of total vascular species), number of endemic genera, and the estimated quantity of native (endemic and indigenous) species for Fiji Island vegetation or species type

	% Land area	% Predicted loss by 2100c	% Endemic species	No. endemic genera	No. native vascular species
Fiji			22-63 ^b	6 ^b	1,290-1,769
Rainforest	33- (65)				
Mangrove^c	2.2	13.7-57.5			(8)
Seagrass					(4-6)

Source: Climate change impacts on native plant communities in Melanesia (Rep. No. 42). Department of Natural Sciences, Bishop Museum Technical (James, 2008).

Whereas an increase in the concentration of carbon dioxide in the atmosphere can rapidly boost the growth rate of green matter (NACCC, 2007). However, these rapid growths of green matter can significantly degrade pastoral nutritional value. Thus, ruminant animals won't receive enough nutrients and pastures that they will need for their growth, maintenance, and reproduction.

Sea level rise and storm surges can cause incursions in saltwater which harms the food products for livestock species and humans. These saltwater incursions include a large concentration of sea salts, involving sulfate, which can eventually change the processes of anaerobic microbial act and composition of the community of plants (Hopfensperger et al., 2014). In the case of chicken livestock production, Fiji (one of the South Pacific Island Countries), increasing in population and demand for chicken meat has enforced many companies to provide breeds at a fast-growing rate, so that they can meet their consumer's needs. However, this is also reduced when climatic changes occur, whereby, extreme weather events cause reduced availability of feed resources which in turn affects the chicken bred diets leading to a decline in their quality and quantity (Vermeulen, 2014).

4.2 Marine Feed Resources

Marine species existence is highly under threat due to climatic changes occurring rapidly. For instance, rise in the sea level, acidification of the ocean; turbidity increase due to coastal water flooding can gradually decrease the availability of seagrasses that are the main diet of sea cow creatures (Masini et al., 2001). Hence, the availability of fewer food resources will cause the sea cow population more susceptible to starvation which will either result in, poor growth, migration of the species or extinction.

Similarly, climate change also affects the tuna fish population in the Pacific region. Many of the Pacific regime countries obtain their major GDP through tuna fisheries production (Bell et al., 2011). According to Gillett (1997), there are 4 main areas of tuna fisheries which includes the Eastern Pacific, Western Indian Ocean, West Africa, and the Pacific Island Countries. Climatic changes like a rise in the temperature of the sea surface, a decline in the concentration of oxygen, and reduced zooplankton and phytoplankton availability can essentially change the feeding grounds and habitats of tuna in the Pacific countries (Cravatte et al., 2009). Therefore, this leads to the migration of tuna populations to other divisions and hence, this will affect the geographic distribution of the species of fish in the Pacific regime. Changes in feeding products will also reduce the healthier growth of fish species.

4.3 A Quarrel Between Human-Animal Feed Resources

Animal and Human conflicts for food resources are becoming more obvious and frequent in the Pacific Island Countries. These quarrels arise due to limited space and feed resources between animals (livestock and marine) and human species. Climatic changes such as droughts, sea-level rise and cyclones lead to resource scarcity which eventually increases the competition between these two species. Clark et al. (2013) have illustrated in one of the reports that the relationship lies between the extinction of pig species and area of land, in which he explained the competition for food led to the extinction of piggeries. Thus, to reduce this competition, humans

living in Pacific Island Countries are now raising pigs in enclosures and pens. Yet, this method is very costly and requires labor. Most farmers in Fiji make snares to hunt pigs due to their laws disallowing them to use guns.

5. How Does Climate Change Affect Animal Behavior?

Behavioral traits of animal species are one of the most important elements regarding their strength towards climatic changes. Biologists have agreed upon the animal behavioral responses to the alterations in the climatic conditions which will determine factors assuming susceptibility of animal species towards climatic threats to biodiversity (Huey et al., 2012). However, records show very less information about animal responses to extreme weather events and variations. Inherent study on the nature of animal behavior is applicable for tackling the complex task of understanding animal diversity response to the changes in the climatic conditions and evaluating effective solutions (Buchholz, 2007).

Numerous animals have already optimized their evolutionary traits through physiological strategies and adapted behaviors to adverse climate changes that will occur over their lifetimes. Animals may be able to depend on their resilience strategies that were previously selected, that is, adaptive phenotypic plasticity, which will help them to face the weather changes. According to Snell-Rood (2013), plasticity is classified as development and activation classes, conceding that behavioral performances may relate to aspects of both classes. The behavioral plasticity under activation class is called flexibility (Swaddle et al., 2016), which permits various activations of a neural network that still exists in different environmental situations. Whereas behavioral plasticity is simply regarded as plasticity only, the output of current behavioral situations has been constrained by experiences in ontogenetic developments. Figure 2 demonstrated below is used as an example that depicts the behavioral aspects of an animal.

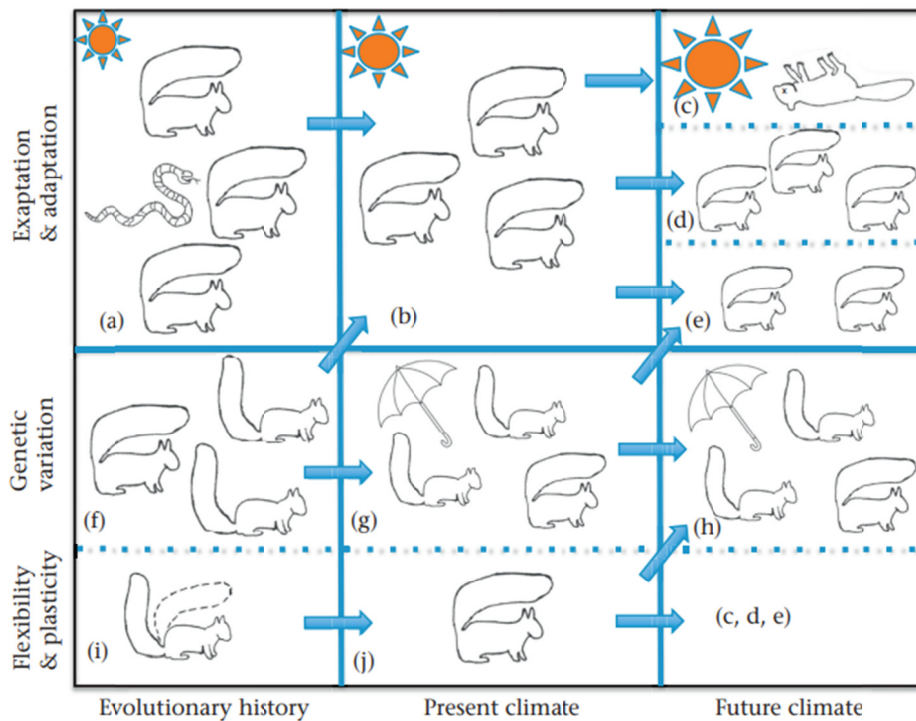


Figure 2. Animal Behavior showing persistence to future climatic conditions

Source: Behavioral research priorities for the study of animal response to climate change, 2019.

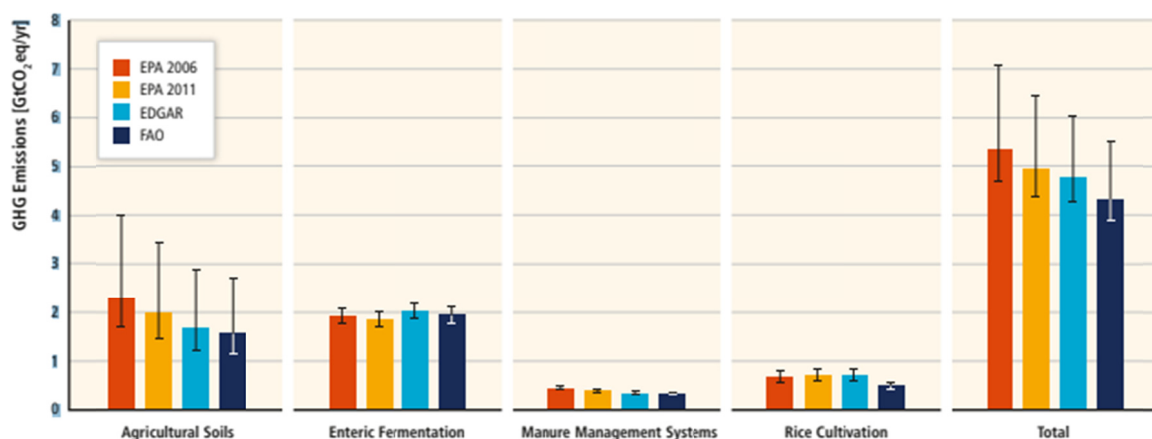
The above figure shows animal population abilities to persist futuristic climatic changes depending on variations in their behavior such as plasticity, flexibility, genetic variation, and evolutionary history. In the above figure, the ground squirrel seemed to shade itself from solar radiation by using its bushy tails as the air temperature increases. (a-b) shows behavioral changes, *i.e.*, situating its tail to the back to appear larger to predatory snakes which will help them to survive warming conditions. (b-d) shows that the adaptation can also be sufficient for them to even survive in hotter conditions. However, (b-e) depicts that it might be insufficient to warming

conditions which will lead to lower recruitment of the population or even may lead to the extinction of that population (b-c). (f) Shows variations in the genes that provide the capability to genetic adaptations to increased warming temperatures. (f-b); evolutionary rescue), yet variation exhaustion because of direct selection can still result in extinction (f, b, c). (i) Animal plasticity responding to climate changes may enforce populations to resist from negative effects of warming conditions (i-j) that can (d, e) or cannot (c) ensure the viability of the population over a long period. Shaded umbrella in (g) depicts populations to evolve slowly over time when the heritable response to selection of genotype is low and the climatic change rates are high. The shaded umbrella also helps to evolve successfully to a phenotype that can survive to hotter climates in future (g-d, e), or else conservation methods will be needed to continue (g and j, to h). Plastic responses to the warmer environment being indistinguishable from the genetic fixation (b) will be very hard to respond to warmer climates (j).

6. What are the Causes of Climate Change?

6.1 Agricultural (Crop)-Human Causes

People always consider how climatic changes affect our ecosystem, but very few realize that climatic changes are not only caused by environmental variations but also through human practices in the environment. Adding on, the agricultural system being practiced now a day's also influence climatic conditions, such as: greenhouse gas emissions, deforestation which leads to loss of habitat to many wildlife species and their biodiversity as well, waterways sedimentation, and poisoning non-targeted species using pesticides (Vermeulen et al., 2012). Agricultural practices, emitting carbon dioxide from burnt plant litter and organic matter, enteric fermentation that releases methane, burning of biomass, manure management and rice production and microbial conversions of nitrogen that produces nitrous oxide to the atmosphere can directly contribute to greenhouse gas emissions (GHG). However, only non-carbon dioxide sources of agriculture are recorded as anthropogenic emission of greenhouse gases, since the actual carbon dioxide released is related to annual cycles of the fixation and oxidation of carbon through the process called photosynthesis (Smith et al., 2014). Therefore, such practices like deforestation and greenhouse gases can highly lead to increased carbon dioxide in the atmosphere which will later result in adverse climatic changes over some time. A graph was developed by (Smith et al., 2014) summarizing the data comparison between Food and Agriculture Organization Corporate Statistical Database (FAOSTAT, 2013), U.S Environmental Protection Agency (U.S. EPA, 2006), and Emission Database for Global Atmospheric Research (EDGAR, 2013) databases for emission categories of agriculture, which was grouped as enteric fermentation, agricultural soils, rice cultivation and manure management systems using IPCC (Intergovernmental Panel on Climate Change) guidelines (IPCC, 2006).



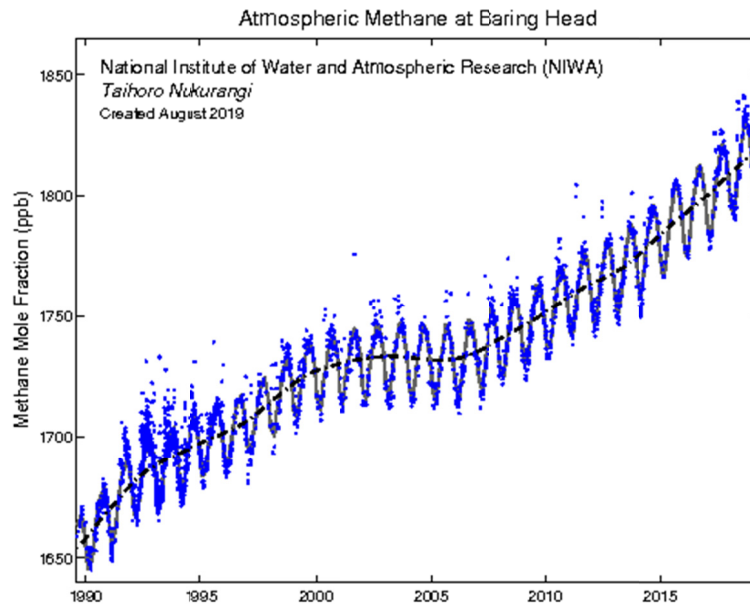
Graph 3. Data comparison between FAOSTAT, U.S EPA, and EDGAR showing agricultural emission categories for GHG emission

Source: Agriculture, Forestry and Other Land Use (AFOLU)—Trends of GHG emissions from agriculture (Smith et al., 2014).

6.2 Livestock-Human Causes

Not only crop agricultural practices but livestock production has a vast impact on the climatic conditions as well. It is one of the detrimental causes of water pollution, deforestation, and biodiversity losses. Livestock production

is the major contributor to methane gas emission into the atmosphere. Adding on, it also emits greenhouse gases compared to other transportation systems. According to Sarah (2019), it was observed in 2019, that performing livestock for milk, eggs and meat contributes 14.5 per cent of greenhouse emissions to the environment. Likewise, livestock by-products significantly release 32,000 million tons of carbon dioxide/year which adversely affects the climatic conditions. Livestock production highly uses around 45 per cent of the total land area which clearly shows the practices of deforestation for livestock farming. Not only this, but meat industrialism also contributes 85 per cent of soil erosion in the world which later affects crop farming practices. Therefore, all these factors are widely associated with climatic changes that are happening rapidly around the world from which all living organisms on earth are highly affected (Sarah, 2019). Graph 4 below is shown as an example that depicts an increase in methane gas due to livestock production over the past years.



Graph 4. Atmospheric methane gas increasing over the years

Source: NIWA, Climate Change and Agriculture. Retrieved from <https://niwa.co.nz/education-and-training/schools/students/climate-change/agriculture>

7. Impact of Climate Change on Animal Reproduction Rate?

7.1 Livestock and Other Terrestrial Organism Reproduction

Climatic changes such as high humidity and temperature affects the cellular functions by altering and impairing various organs and tissues of the reproductive system in both (male and female) animals. Vulnerability to climatic changes is much higher in the reproductive functions of livestock. Not only this, the functions and rhythm of the reproductive system are also affected by heat stress, high temperature and intensity of radiant load (Amundson et al., 2006; Sprott et al., 2001).

Similarly, climatic changes such as an increase in temperature level, rainfall periods and others can highly affect other terrestrial organisms. These types of climatic changes particularly concern species that depend on climatologically events. Thus, alterations in the climate can boost behavioral changes, such as; migration or either reproduction, which later on leads to a decline in the species population since they are not able to reproduce in the changed climatic conditions (Plummer et al., 2015).

7.2 Marine Reproduction

According to Schiff (2020), “many marine animals like sea urchins, corals, and clown fish rely on water conditions for reproduction because they reproduce externally, meaning the eggs are fertilized outside of the animals’ body in the water. These animals depend on specific cues and conditions in their environment to signal mating season. Currents, temperature, salinity, light, and acidity are all factors that dictate when and how successfully different marine organisms reproduce”, [Oceanic organisms like clownfish highly depend on the

conditions of water for their reproduction since they reproduce outside their body. These kinds of animals rely on a particular condition that signals their mating season. Temperature, light, salinity and acidity provide the right time to mate, thus climatic changes influencing these factors affect the mating period as a whole]. Schiff (2020) also mentioned “that many fish, including salmon, bluefin tuna, and swordfish, rely heavily on temperature to signal spawning, the release of eggs and sperm into the water”, [Several fish species involving tuna fish, salmon and others depend on the temperature to indicate spawning (egg and sperm release in water)]. An increase in the temperature level will indicate earlier development of reproduction in the species that spawn during spring and thus, shortening the period of spawning, which results in less mating rate. The ocean absorbs gas from the atmosphere, that is, carbon dioxide, but chemical reactions that occur between carbon dioxide and water produce and increase the acidity in the ocean, influencing the function of pheromones (love potion) which is used to attract mates. Therefore, these conditions affect the reproductive system and its period which later reduces the population size of a marine organism (Schiff, 2020).

8. Impact of Climate Change on Animal Mortality?

Numerous studies have indicated that climate change can harm animal health as well which later contributes to increased mortality. The effect can be either direct or indirect which may be due to primarily alterations in the environment, including relative humidity, air temperature, precipitation, and the frequency of these extreme events (Forastiere, 2010).

8.1 Direct Effects of Climate Change

Listed below are the direct effects of climate change on animal health.

8.1.1 Metabolic Disorder Effects

Animals (homoeothermic) react to increased temperature by boosting the heat loss and declining the production of heat for them to avoid high body temperature. Such reactions involve sweating and respiratory rate increase and a decline in the intake of food. These occurrences define significant contribution to the event of metabolic disorders in animals that are stressed through heat. Thus, this heat stress leads to lameness in beef and dairy cows (Shearer, 1999). Feed intake reduction collaborative with the boosted expenditure of energy for maintenance can highly affect the energy balance in an animal's body which in return will cause the animals to lose bodyweight and thus, the rapid occurrence of these events will, later on, contribute to animal mortality (Lacetera et al., 2002).

8.1.2 Oxidative Stress Effects

Pathological conditions like animal production and individual welfare may be affected by oxidative stresses (Lykkesfeldt & Svendsen, 2007). This event usually occurs when there is an imbalance between antioxidants and oxidants. From the past years, (2002 onwards) there has been a great interest in the research of heat stress that induces oxidative effects in farm animals, thus, leading to unhealthier conditions that result in mortality (Bernabucci et al., 2002).

8.1.3 Suppression of Immune System

The involvement of the immune system in many animals has helped them to halt the invasion of pathogens in their body. However, heat stress can influence the immune system vastly, whereby; it can impair the immune functions in animals producing food (Lacetera, 2012). However, influencing the immune system through heat stress depends on different types of breeds, species, age, genotype intensity and duration of animals exposed to unfavourable conditions. The suppression of the immune system leads to infections, which breaks the efficiency of the reproductive system and may cause a decline in animal welfare and increase the usage of anti-microbial. When there is high usage of antimicrobials, the pathogens start to become resistant and hence, they cause more infections.

8.1.4 Death

Numerous studies have reported a greater chance of mortality during hot seasons and extreme weather conditions. Heatstroke, heat cramps, heat exhaustion and organ dysfunctions are all caused by high-temperature events. These complexities appear when the temperature of the body increases 3-4 °C above the normal body temperature. According to Purusothaman et al. (2008), the mortality rate of Mecheri sheep occurs when it is the time of summer. Another series of studies were described by (Hahn & Mader, 1997), whereby, they also found that the mortality rate of livestock increases during extreme heat-wave events.

8.2 Indirect Effects of Climate Change

As discussed earlier, climatic changes affect the distribution and biology of infectious diseases like a vector-borne diseases. For instance, precipitation changes, temperature boosting, and relative humidity will

influence more reproduction of insects leading to higher population density. Therefore, diseases that are transmitted by insects, may mobilize themselves from their natural habitat to other countries. Wittmann et al. (2001) described an increase of temperature level by 2 degrees indicates a large spread of *Culicids' imicola*, which defines the main bluetongue virus vector. This virus stimulates arthropod-borne disease that affects wild and domestic ruminants. Therefore, increasing the mortality rate in livestock species.

9. Way Forward

There have been many aspects of climatic changes that have affected the animal production sector in several ways and so Fiji citizens and its government-created possible ways to overcome these scenarios not only in the present time but in future as well.

9.1 Solution for Livestock and other Terrestrial Organisms

Below are some of the methods carried out to revive the situations of climatic changes.

9.1.1 Workshop—Carried Out in Nabua, Suva Based on Adaptation in the Livestock Sector by SPC (2011)

In this workshop, group division was carried out between the participants who were assigned to obtain the adaptation methods for each climate change in sectors such as cattle, dairy, local pigs, broilers and layers, small ruminants and lastly, local poultry. They were able to determine and map the risks and threats of the climatic hazards, such as droughts, sea-level rise, rise in the temperature value, flooding, and cyclones. Through their mapping of research, they were able to indicate some of the adaptation ways for futuristic benefits in the livestock sector, which includes.

- Cattle: containing those crossbreeds which are tolerant to heat, lower exposure to disease infections, tolerant to drought and heat stress as well. Secondly, maintaining maximum availability and quality through water management practices by establishing well gutters or tanks and new ways to obtain water resources.
- Swine: obtaining good house locations and designs. Likewise, good water management practices as well such as water tanks, water pumps and boreholes. Proper sanitation and hygiene with good husbandry practices like observing the rates of stock, managing the feeding process, and keeping appropriate records were also determined by the participants.
- Commercial poultry: improving the feeding availability that is highly nutritional and can replace compound feeds. Secondly, designing shed areas associated with climate vulnerabilities so that poultry site areas could be improved for their production. Like cattle breeds, the participants also determined that resistant breeds should be more to survive climatic hazards.

9.1.2 Projected Climate Change Impacts on Animal Production

Through research, it has been recorded that highly output breeds that were introduced in the Pacific region including Fiji are not well tolerated and adapted to heat stress and other climatic conditions (Frank et al., 2001). Thereby, research and evaluations were carried out to bring betterments in animal production through projecting climatic impacts which will help later in determining what to be done before any climatic conditions will arise again and destroy our animal species in Fiji and the Pacific as a whole.

Many farmers have already started to practice mixed crop production with the livestock system in terms of their knowledge. Adding on to that some other aspects have been determined to adapt for climatic conditions such as breeding (bringing of new traits that are well adapted), adaptation to feeding and nutrition's and shelter and water management practices (Thornton et al., 2009; SPC, 2011). Below is Table 5 that shows the projected impacts of climate change.

Table 5. Projects impacts of climatic changes on animal production

Climate Change	Projected Impact 2030	Projected Impact 2050	Projected Impact 2090
Rising sea level	Saltwater intrusion into groundwater will reduce potable drinking supplies for livestock and impact on quality and quantity of available feed.	Some coastal land may become unsuitable for agricultural production. Increasing stock densities and closer human/animal contact with increased risk of disease transfer especially on smaller atolls.	Further reduction of land suitable for agricultural production. The concentration of agricultural production in the remaining areas. Greater reliance on food imports.
Increasing temperature	Minimal effect on indigenous locally adapted breeds. Survival of native bee species adapted to cooler temperatures of higher elevations may be compromised with impacts on the survival of plant species dependent on these species for pollination. Actual temperature tolerances are unknown. Changes in the geographical extent, population, life cycle and transmission of livestock diseases and pests depend on the specific temperature tolerances.	Temperature gains of up to 2.0 °C may lead to species/breed substitution, especially of temperate breeds/species. Seasonal and spatial distribution, composition and patterns of forage species will change. With the global production of maize and other coarse grains likely to be adversely affected by higher temperatures, climate change could have a significant impact on the availability/reliability of local livestock feed. As for 2030 re pest and disease impacts. Increased risk of food-borne disease-related illness.	As for 2050. Temperature gains of up to 4 °C are likely to require species/breed substitution. Livestock with low-temperature comfort zones such as Bos taurus dairy breeds and chickens are particularly vulnerable.
Heatwaves	Potential to reduce the productivity of introduced temperate latitude breeds although in commercial/semi-commercial systems the effects can be managed through climate control and other practices. Provision of shelter and water will be necessary for traditional systems to avoid a reduction in production and/or stock death	Increased likelihood of animal death especially in tethered or confined traditional production systems. Commercial systems will need to invest more in cooling systems to avoid substantial loss of stock.	As for 2030. Likely need for species/ breed substitution.
More frequent and intense droughts	Reduction in the quality and quantity of available forage. Seasonal and spatial distribution, composition and patterns of forage species will change. Increased grazing pressure on areas where feed is available may lead to environmental side effects (e.g., erosion) and increased risk of disease transfer. Reduced quality and quantity of drinking water. Increased competition between various water users.	As for 2030	As for 2030
More frequent and intense floods, higher rainfall	Infrastructure damage (roads, buildings, fences, etc.). Increased human and animal health risk from waterborne diseases. Reduced animal mobility. Reduced feed availability and quality through flooding and spoilage of stored feed.	As for 2030	As for 2030
Increasing CO₂ concentration	Unknown	Unknown	Reduction in the quality and composition of forage/ feed types due to a gradual shift from C3 to C4 species. Increased lignification of plant tissue (i.e., reduced quality).

Source: Vulnerability of Pacific Island agriculture and forestry to climate change (SPC, 2016).

9.2 Solution and Adaptations for Marine Organisms

Effective management of fisheries and other marine organism sectors can be obtained through implementing climatic resilient organisms (Hilborn et al., 2011). The management involves numerous tasks that should aim to enhance the sustainable use of marine organisms such as fish and crabs to diversify societal goals. Managing the marine organisms concerning adverse climatic effects is hence a special decision-making process whereby, additional risks and threats must also be addressed which will, later, help in performing good management practices against extreme climatic events. Such management practices include:

- Planning and implementing phase: this involves the understandability of risks that occur due to climatic changes on marine organisms, assessing those risks, evaluating the final assessment done and identifying potential hazard managements that can act upon the climatic conditions. Then, implementing those management methods into action and observing if those practices are able beneficial for the adaptation of marine organisms or not.
- Adaptive management approaches: this considers the management of resources as experiments, through which the managers can learn and make corrective changes such as policies (Walters, 1986). The systems for management practices against extreme climatic events have been designed to fluctuate the oceanic resources for better adaptation between marine organisms. However, climatic changes rule over these assumptions by changing the resource availability of the species. However, it is very important to have clear adaptation measurements to recover from such events happening around the ocean. For instance, coastal habitats of fisheries have been highly impacted through climatic changes in coastal areas and overfishing as well, thus, educating fishermen and individuals not to overfish may reverse the degradation of habitats and increase their populations leading to higher adaptation of the species towards climatic changes and thus, both the coastal zone and fisheries have been managed properly.

Thereby, the above practices implemented show an effective way of overcoming climatic events that are happening around Fiji.

10. Conclusion

As discussed in the above content, climate change can highly affect livestock, other terrestrial and marine organisms' production in numerous ways leading to a decline in their feeding quality, growth, health conditions, and productivity which later results in behavior changes and mortality. These degradations happening in the animal production sector not only affect the livelihood of many individuals in Fiji but also influences and decreases the economic growth of the country and other areas of the Pacific region. Extreme weather events have been happening over many decades, yet we haven't been able to recover from the past events which bring into the necessity of doing such measurements that can not only help in recovering from the past events but can also help in the future for retaining the animal species around us.

Consequently, the Government of Fiji associated with the Secretariat of Pacific Community developed strategies like workshops to implement the risk of climatic hazards and how to overcome those scenarios. These workshops, predictions made for future climatic conditions and adaptive methods will not only help the government to revive from these climatic conditions but will also educate farmers performing animal production to practice safer management practices to fight against extreme weather conditions.

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Reference

- Acetera, N., Bernabucci, U., Ronchi, B., & Nardone, A. (1996). *Body condition score, metabolic status and milk production of early lactating dairy cows exposed to warm environment* (pp. 43-55). Riv. Agric. Subtrop. Trop.
- Amundson, J. L., Mader, T. L., Rasby, R. J., & Hu, Q. S. (2006). Environmental effects on pregnancy rate in beef cattle. *Journal of Animal Science*, 84(12), 3415-3420. <https://doi.org/10.2527/jas.2005-611>
- Asian Development Bank. (2013). *The Economics of Climate Change in the Pacific*. Retrieved from <http://www.adb.org>
- Bell, J. (2011). Implications of climate change for contributions by fisheries and aquaculture to Pacific Island economies and communities. *Vulnerability of tropical Pacific fisheries and aquaculture to climate change* (pp. 733-801). Secretariat of the Pacific Community, Noumea.

- Bernabucci, U., B, R., Lacetera, N., & Nardone, A. (2002). Markers of oxidative status in plasma and erythrocytes of transition dairy cows during hot season. *J. Dairy Sci.*, *85*, 2173-2179. [https://doi.org/10.3168/jds.S0022-0302\(02\)74296-3](https://doi.org/10.3168/jds.S0022-0302(02)74296-3)
- Buchholz, R. (2007). Behavioral biology: An effective and relevant conservation tool. *Trends in Ecology and Evolution*, *22*(8), 401-407. <https://doi.org/10.1016/j.tree.2007.06.002>
- Buchholz, R., Banusiewicz, J. D., Burgess, S., Crocker-Buta, S., Eveland, L., & Fuller, L. (2019). Behavioural research priorities for the study of animal response to climate change. *Animal Behaviour*, *150*, 127-137. <https://doi.org/10.1016/j.anbehav.2019.02.005>
- Bakare, A. G., Kour, G., Akter, M., & Iji, P. A. (2020). Impact of climate change on sustainable livestock production and existence of wildlife and marine species in the South Pacific Island Countries: A review. *International Journal of Biometeorology*, *64*(8), 1409-1421. <https://doi.org/10.1007/s00484-020-01902-3>
- Christensen, L., Coughenour, M. B., Ellis, J. E., & Chen, Z. Z. (2004). Vulnerability of the Asian Typical Steppe to Grazing and Climate Change. *Climatic Change*, *63*(3), 351-368. <https://doi.org/10.1023/b:clim.0000018513.60904.fe>
- Clark, P. F., Hawkins, Reepmeyer, C., Smith, I., & Masse, W. B. (2013). Distribution and extirpation of pigs in Pacific Islands: A case study from Palau. *Archaeology in Oceania*, *48*(3), 141-153. <https://doi.org/10.1002/arco.5012>
- Climate Change and Agriculture. (2021). Retrieved December 3, 2021, from <https://niwa.co.nz/education-and-training/schools/students/climate-change/agriculture>
- Government of Fiji, World Bank, and Global Facility for Disaster Reduction and Recovery. (2017). *Climate Vulnerability Assessment—Making Fiji Climate Resilient*. Retrieved from <http://www.ourhomeourpeople.com>
- Cravatte, S., Delcroix, T., Zhang, D., Mcphaden, M., & Leluop, J. (2009). Observed freshening and warming of the Western Pacific Warm Pool. *Climate Dynamics*, *33*(4), 565-589. <https://doi.org/10.1007/s00382-009-0526-7>
- da Silveira Pontes, L., Maire, V., Schellberg, J., & Louault, F. (2015). Grass strategies and grassland community responses to environmental drivers: A review. *Agronomy for Sustainable Development*, *35*(4), 1297-1318. <https://doi.org/10.1007/s13593-015-0314-1>
- Easterling, D. R., Karl, T. R., Gallo, K. P., Robinson, D. A., Trenberth, K. E., & Dai, A. (2000). Observed Climate Variability and Change of Relevance to the Biosphere. *Journal of Geophysical Research: Atmospheres*, *105*(D15), 20101-20114. <https://doi.org/10.1029/2000jd900166>
- Easterling, W., P. A., & Brander, K. (2007). *Climate change 2007: Impacts, adaptation and vulnerability* (Rep., pp. 273-313). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.
- FAO (Food and Agriculture Organization of the United Nations). (2008). *Climate Change and Food Security in Pacific Island Countries*. Food and Agriculture Organization of the United Nations, Rome.
- Fischer, E. M., & Schär, C. (2010). Consistent geographical patterns of changes in high-impact European heatwaves. *Nature Geoscience*, *3*(6), 398-403. <https://doi.org/10.1038/ngeo866>
- Fiji-Country Commercial Guide. (2021). *Agriculture Sector*. International Trade Administration. Retrieved from <https://www.trade.gov/country-commercial-guides/fiji-agriculture-sector>
- Forastiere, F. (2010). Climate change and health: a challenge for epidemiology and public health. *International Journal of Public Health*, *55*(2), 83-84. <https://doi.org/10.1007/s00038-009-0096-9>
- Gillett, R. (1997). The importance of tuna to Pacific Island Countries. *Forum Fisheries Agency* (Rep.). Honiara, Solomon Islands.
- Giridhar, K., & Samireddypalle, A. (2015). Climate Change Impact on Livestock: Adaptation and Mitigation. In V. Sejian, J. Gaughan, L. Baumgard, & C. Prasad (Ed.), *Impact of Climate Change on Forage Availability for Livestock* (pp. 97-112). Springer, New Delhi. https://doi.org/10.1007/978-81-322-2265-1_7
- Gutierrez, N. L., Hilborn, R., & Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature*, *470*(7334), 386-389. <https://doi.org/10.1038/nature09689>

- Hahn, G., & Mader, T. L. (1997). Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. *Proceedings of the 5th International Symposium* (pp. 563-571). St Joseph (MI): ASAE.
- Harvell, C. D., Mitchell, C. E., Ward, J. R., Altizer, S., Dobson, A. P., Ostfeld, R. S., & Samuel, M. D. (2002). Climate Warming and Disease Risks for Terrestrial and Marine Biota. *Science*, 296(5576), 2158-2162. <https://doi.org/10.1126/science.1063699>
- Hoberg, E. P., Polley, L., Jenkins, E. J., & Kutz, S. J. (2008). Consecuencias del Cambio Climatico Mundial en Los Patogenos de Ungulados Criados en Fincas o en Libertad en Las Regiones Templadas y Boreales De America Del Norte. *Revue Scientifique et Technique*, 27(2), 511-528. <https://doi.org/10.20506/rst.27.2.1818>
- Hopfensperger, K. N., Burgin, A. J., Schoepfer, V. A., & Helton, A. M. (2014). Impacts of Saltwater Incursion on Plant Communities, Anaerobic Microbial Metabolism, and Resulting Relationships in a Restored Freshwater Wetland. *Ecosystems*, 17(5), 792-807. <https://doi.org/10.1007/s10021-014-9760-x>
- Huey, R. B., Kearney, M. R., Krockenberger, A., Holtum, J. A., Jess, M., & Williams, S. E. (2012). Predicting organismal vulnerability to climate warming: Roles of behavior, physiology and adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 367(1596), 1665-1679. <https://doi.org/10.1098/rstb.2012.0005>
- Igbal, M. R. (2021). Bovine Mastitis in Fiji: Economic Implications and Management—A Review. *Journal of Agricultural Science*, 13(10), 162. <https://doi.org/10.5539/jas.v13n10p162>
- Igbal, M. R. (2022). The Economic Impact of Climate Change on the Agricultural System in Fiji. *Journal of Agricultural Science*, 14(2), 144. <https://doi.org/10.5539/jas.v14n2p144>
- IPCC. (2013). *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Rep.). Cambridge University Press, Cambridge, United Kingdom; New York, United States of America. <https://doi.org/10.1017/CBO9781107415416.005>
- IPCC (Intergovernmental Panel on Climate Change). (2014). Summary for policymakers. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects* (pp. 1-32). Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. <https://doi.org/10.1017/CBO9781107415416>
- IPCC (Intergovernmental Panel on Climate Change). (2014). In Working Group III & O. Edenhofer (Eds.), *Climate change: Mitigation of climate change* (p. 359). Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
- James, S. (2008). *Climate change impacts on native plant communities in Melanesia* (Rep. No. 42). Department of Natural Sciences. Bishop Museum Technical.
- Jupiter, S., Mangubhai, S., & Kingsford, R. T. (2014). Conservation of Biodiversity in the Pacific Islands of Oceania: Challenges and Opportunities. *Pacific Conservation Biology*, 20(2), 206. <https://doi.org/10.1071/pc140206>
- King, J. M., Parsons, D. J., Turnpenny, J. R., Nyangaga, J., Bakari, P., & Wathes, C. M. (2006). Modelling energy metabolism of Friesians in Kenya smallholdings shows how heat stress and energy deficit constrain milk yield and cow replacement rate. *Animal science*, 82(5), 705-716. <https://doi.org/10.1079/asc200689>
- Knoema. (2020). *Fiji—Production of milk*. World Data Atlas. Retrieved From <https://knoema.com/atlas/Fiji/topics/Agriculture/Live-Stock-Production-Production-Quantity/Production-of-milk>
- Lacetera, N. (2012). Effect of environment on immune functions. In R. J. Collier & J. L. Collier (Eds.), *Environmental physiology of livestock* (pp. 165-179). Chichester, England: Wiley-Blackwell. <https://doi.org/10.1002/9781119949091.ch9>
- Lykkesfeldt, J., & Svendsen, O. (2007). Oxidants and antioxidants in disease: Oxidative stress in farm animals. *The Veterinary Journal*, 173(3), 502-511. <https://doi.org/10.1016/j.tvjl.2006.06.005>
- McGregor, A., & Dawson, B. (2016). *Vulnerability of Pacific Island agriculture and forestry to climate change*. Fiji: SPC (Secretariat of the Pacific Community).
- Mary, T., Andrew, M., & Brian, D. (2016). *Vulnerability of Pacific Island agriculture and forestry to climate change*. Fiji: SPC (Secretariat of the Pacific Community).

- Masini, R. J., Anderson, P. K., & McComb, A. J. (2001). A Halodule-dominated community in a subtropical embayment: Physical environment, productivity, biomass, and impact of dugong grazing. *Aquatic Botany*, 71(3), 179-197. [https://doi.org/10.1016/s0304.3770\(01\)00181-4](https://doi.org/10.1016/s0304.3770(01)00181-4)
- Mercier, E., & Salisbury, G. (1947). Seasonal Variations in Hours of Daylight Associated with Fertility Level of Cattle under Natural Breeding Conditions. *Journal of Dairy Science*, 30(10), 747-756. [https://doi.org/10.3168/jds.s0022-0302\(47\)92395-3](https://doi.org/10.3168/jds.s0022-0302(47)92395-3)
- Montzka, S. A., Dlugokencky, E. J., & Butler, J. H. (2011). Non-CO₂ greenhouse gases and climate change. *Nature*, 476(7358), 43-50. <https://doi.org/10.1038/nature10322>
- Morgan, J. A., Milchunas, D. G., Lecain, D. R., West, M., & Mosier, A. R. (2007). Carbon Dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. *Proceedings of the National Academy of Sciences*, 104(37), 14724-14729. <https://doi.org/10.1073/pnas.0703427104>
- Lakhan, H. (2011). *Livestock & climate change in the Pacific island region* (Rep.). Suva: Secretariat of the Pacific Community.
- NACCC. (2007). *National Adaptation Program for Action GEF/UNDP/UNFCCC/NACCC*. Republic of Vanuatu.
- Pilling, D., & Hoffmann, I. (2011). *Climate Change and Animal Genetic Resources for Food and Agriculture: State of Knowledge, Risks and Opportunities* (Paper No. 53). FAO Commission on Genetic Resources for Food and Agriculture, Rome, Italy.
- Plummer, K., Siriwardena, G., Conway, G., Risely, K., & Toms, M. (2015). Is supplementary feeding in gardens a driver of evolutionary change in a migratory bird species? *Global Change Biology*, 21(12), 4353-4363. <https://doi.org/10.1111/gcb.13070>
- Pritchard, H. D., Ligtenberg, S. R., Fricker, H. A., Vaughan, D. G., Broeke, M. R., & Padman, L. (2012). Antarctic ice-sheet loss driven by basal melting of ice shelves. *Nature*, 484(7395), 502-505. <https://doi.org/10.1038/nature10968>
- Purusothaman, M., Thiruvengadan, A. K., & Karunanithi, K. (2008). Seasonal variation in body weight and mortality rate in Mecheri adult sheep. *Livestock Research for Rural Development*, 20(9). Retrieved from <http://www.lrrd.org/lrrd20/9/thir20150.htm>
- Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives. *Atmospheric Environment*, 43(1), 37-50. <https://doi.org/10.1016/j.atmosenv.2008.09.063>
- Reddy, M. (2007). *Enhancing the agricultural sector in Pacific island economies* (Vol. 22, No. 3). Fiji: Pacific Economic Bulletin.
- Sarah, B. (2019). *How Livestock Farming Affects the Environment*. Down to Earth. Retrieved from <https://www.downtoearth.org.in/factsheet/how-livestock-farming-affects-the-environment-64218>
- Schiff, J. (2020). *Climate Change: The Ocean's "Mood Killer"*. Retrieved from <https://sitn.hms.harvard.edu/flash/2020/climate-change-the-oceans-mood-killer>
- Shearer, J. (1999). *Foot health from a veterinarian's perspective* (pp. 33-43). Proc. Feed Nutr. Manag. Cow Coll. Virg. Tech.
- Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., ... Tubiello, F. N. (2014). Climate Change 2014: Mitigation of Climate Change. *Agriculture Forestry and Other Land Use (AFOLU)*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom; New York, United States of America.
- Snell-Rood, E.C. (2013). An overview of the evolutionary causes and consequences of behavioural plasticity. *Animal Behaviour*, 85(5), 1004-1011. <https://doi.org/10.1016/j.anbehav.2012.12.031>
- SPC (Secretariat of the Pacific Community). (2006). *Oceanic Fisheries Program, Climate and Tuna Fisheries*. Secretariat of the Pacific Community, Noumea, New Caledonia.
- SPC (Secretariat of the Pacific Community). (2011). *Livestock & Climate Change in the Pacific Island Region* (Rep.). Suva: Secretariat of the Pacific Community.
- Sprott, L. R., Selk, G. E., & Adams, D. C. (2001). Review: Factors affecting decisions on when to calve beef females. *The Professional Animal Scientist*, 17, 238-246. [https://doi.org/10.15232/S1080-7446\(15\)31635-1](https://doi.org/10.15232/S1080-7446(15)31635-1)

- Swaddle, J. P. (2016). Evolution and conservation behavior. *Conservation Behavior*, 36-65. <https://doi.org/10.1017/cbo9781139627078.004>
- Taylor, S., & Kumar, L. (2016). Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: A Review. *Tropical Conservation Science*, 9(1), 203-223. <https://doi.org/10.1177/194008291600900111>
- Thomas, A. S., Mangubhai, S., Vandervord, C., Fox, M., & Nand, Y. (2018). Impact of Tropical Cyclone Winston on women mud crab fishers in Fiji. *Climate and Development*, 11(8), 699-709. <https://doi.org/10.1080/17565529.2018.1547677>
- Thornton, P., Steeg, J. V., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, 101(3), 113-127. <https://doi.org/10.1016/j.agsy.2009.05.002>
- Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: A review. *Global Change Biology*, 20(11), 3313-3328. <https://doi.org/10.1111/gcb.12581>
- The Fijian Government. (2014). *Farm Help Improves Milk Production (Feature from Agriculture Market Watch)*. Retrieved from <https://www.fiji.gov.fj/media-centre/news/farm-help-improves-milk-production>
- The Fijian Government. (2021). *Dairy Expansion Vital to Boost Milk Production*. Retrieved from <https://www.fiji.gov.fj/media-centre/news/dairy-expansion-vital-to-boost-milk-production>
- Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M., & Roeckner, E. (1999). Increased El Niño frequency in a climate model forced by future greenhouse warming. *Nature*, 398(6729), 694-697. <https://doi.org/10.1038/19505>
- Tubiello, F., & Soussana, J. (2007). Crop and pasture response to climate change. *Proceedings of the National Academy of Sciences of the United States of America*.
- Van Dijk, J., Sargison, N., Kenyon, F., & Skuce, P. (2010). Climate change and infectious disease: Helminthological challenges to farmed ruminants in temperate regions. *Animal*, 4(3), 377-392. <https://doi.org/10.1017/s1751731109990991>
- Vermeulen, S. (2014). *Climate Change, Food Security and Small-Scale Producers: Analysis of Findings of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) CCAFS Info Brief*. Research Program on Climate Change, Agriculture and Food Security (CCAFS), Denmark.
- Vermeulen, S., Aggarwal, P., Ainslie, A., Angelone, C., Campbell, B., Challinor, A., ... Wollenberg, E. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, 15(1), 136-144. <https://doi.org/10.1016/j.envsci.2011.09.003>
- Walters, C. (1986). *Adaptive Management of Renewable Resources*. MacMillan, New York.
- Wittmann, E., & Baylis, M. (2000). Climate Change: Effects on Culicoides-Transmitted Viruses and Implications for the UK. *The Veterinary Journal*, 160(2), 107-117. [https://doi.org/10.1016/s1090-0233\(00\)90470-2](https://doi.org/10.1016/s1090-0233(00)90470-2)
- Wittmann, E., Mellor, P., & M, B. (2001). Using climate data to map the potential distribution of *Culicoides imicola* (Diptera: Ceratopogonidae) in Europe. *Rev. Sci. Tech.*, 731-740. <https://doi.org/10.20506/rst.20.3.1306>

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