



Food systems in the face of climate change: reviewing the state of research in South Pacific Islands

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Received: 9 September 2022 / Accepted: 24 January 2023 / Published online: 20 February 2023
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Abstract

Food security, in the context of a rapidly changing climate, is one of the most prominent global challenges facing human societies today. Pacific Island Countries and Territories (PICTs) are particularly vulnerable to the adverse effects of climate change, while facing additional stress from globalisation and increased supply chain disruption. This review aims to document our understanding of food system vulnerability to climate change in the region, and identify the existing studies that could inform policy and decision-making. The review also serves to discern the dominant focal areas of research, as well as where gaps exist for emerging research.

Using keyword searches on the web, scholarly databases, and targeted organisational websites, we identified 104 studies published from 2010 to 2022 that looked at the impacts of climate change on some aspect of the food system in at least one PICT. We found that the majority of empirical research on climate impacts on food systems in PICTs focused on the biophysical components of food production rather than the complex interactions between the socio-economic and biophysical factors that make up food systems. An incomplete understanding of the impacts from climate change could result in maladaptation and an undermining of food system resilience.

Keywords Climate change · Food systems · Vulnerability · Pacific Island Countries and Territories · Adaptation

Introduction

The impact of climate change on food systems and food security is one of the most pressing global challenges facing human societies today. Climate change is expected to impact food supply, likely resulting in increased food prices globally, and affecting food security (Mbow et al. 2019). Therefore, it is crucial to understand the current evidence of climate change impacts on food security to effectively inform policy and decision-making that supports the ability of food systems to ensure the accessibility of safe and

nutritious food (Mbow et al. 2019). The importance of taking a systems approach to human food and nutrition security is strongly supported in the literature (Ericksen 2008; Ingram 2011) and policy discourses (De Schutter et al. 2015; FAO et al. 2020). However, the application of food systems frameworks in empirical research is less well-established, particularly in relation to understanding the impacts of climate change and possible solutions. This is especially the case in Pacific Island Countries and Territories (PICTs), which are especially vulnerable to the adverse effects of climate change, and already face food and nutrition security challenges (Mycoo et al. 2021).

This review aims to canvas the published research on climate change impacts on food systems in PICTs, and seeks to understand the extent to which this research employs systems approaches. This benchmarking exercise is crucial to inform adaptation planning processes, as well as identify key research gaps for further investment and investigation. However, there is currently no systematic review on this topic for the PICTs region. Much of our understanding of climate change impacts is captured in the Intergovernmental Panel on Climate Change reports, which have minimal coverage

Communicated by Prajal Pradhan

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of the PICTs (Mycoo et al. 2021). Other studies that try to synthesise food systems vulnerability to climate change in PICTs take a high-level approach to impacts on agriculture, fisheries, and food security, and focus less on the state of the evidence and gaps in the research (Barnett 2011).

In this review, we first conceptualise systems approaches to food security and define the components of the food systems. This is followed by a description of the methods and the general findings. We conclude with a discussion reflecting on the gaps and potential opportunities in food security research that could help pave the way for future research and programming to better support the resilience of food systems in the face of global change.

Systems approaches to food and nutrition security

It is increasingly recognised that the world's major challenges, from human health and food insecurity to environmental degradation and climate change, are fundamentally interconnected (Liu et al. 2018). An integrated or “systems” approach enables accounting for the connections, synergies, and trade-offs between different sectors, activities, or components. In the context of food and nutrition security outcomes, the dominant modes of research and practice have a strong focus on the biophysical aspects of food production, and are therefore predisposed to draw more simplistic or single-issue conclusions, which may limit their practical relevance (“Systems thinking, systems doing,” 2020). In contrast to these supply-focused and linear approaches, systems thinking can bring interdisciplinary perspectives to food and nutrition security, treating it as a product of complex interactions (Brouwer et al. 2020). Scholars therefore argue that systems approaches, which account for this complexity inherent in achieving such outcomes, better approximate on-the-ground realities and contribute to adaptation and building resilience over time (Tendall et al. 2015).

From a conceptual standpoint, using a systems framework allows for the development of adaptation pathways that consider synergies and trade-offs between natural resources and environmental outcomes and food security and welfare outcomes, thereby increasing adaptive capacity (Ingram 2011). Non-systems-oriented solutions, such as a solitary focus on agricultural practices to address food shortages, could ignore the feedbacks between system components and lead to increased vulnerabilities down the line, such as soil erosion and malnutrition. Adaptation responses for food and nutrition security that address the nexus between social, ecological, and economic factors have been proposed as contributing to “no-regrets” outcomes, simultaneously reducing vulnerability and increasing resilience (Ingram 2011). Coordination of adaptation responses across a food system can reduce the possibility of creating vulnerabilities

in connected parts of the food supply chain or consumer environment.

What is a food system?

The concept of food systems has been gaining traction as a framing for food security discourses, notably since around 2008 (Ericksen 2008; Ingram 2011). The primary role of a food system is to achieve food security—when “all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life” (Pinstrup-Andersen 2009). Food systems broadly can be defined as the interactions between and within human-centred and bio-geophysical dimensions related to achieving this goal, and are composed of both environmental and socio-economic components (Ericksen 2008). A food system is made up of all elements (e.g. actors, inputs, infrastructure, institutions, processes), activities (including production, manufacturing, transport, retailing and processing activities), and outcomes related to food (Mbow et al. 2019; Robins et al. 2020). Food system components are interdependent; for instance, food consumption depends on functional production activities, such as agricultural production, food processing, and distribution to markets. Previous studies have argued that, as a result of how interconnected food system actors and activities are, interventions that reduce one vulnerability may create vulnerabilities in another part of the system (Paloviita et al. 2017).

For the purpose of this study, “food systems” is divided into three broad components: “on-farm production”, “off-farm supply”, and “food environment” (Fig. 1). On-farm production activities include subsistence and commercial agriculture, livestock, agroforestry, coastal, oceanic, and inland freshwater fisheries, and other mixed systems (e.g. silvo-pastoralism, integrated crops and aquaculture). The off-farm supply component comprises the physical elements and activities following production along food supply chains. These include processing, transport, storage, markets, and the associated infrastructure and labour. Finally, food environments are defined as the “collective physical, economic, policy, and socio-cultural surroundings, opportunities, and conditions that influence people’s food and beverage choices and nutritional status” (Turner et al. 2018). A food environment therefore connects food supply and demand, and is composed of food availability, affordability, social preferences, quality, safety, messaging, and traditional or cultural factors. Food and nutrition security is considered an outcome of the interactions of all the food system components.

Climate change in the Pacific Island Countries and Territories

Mitigating and adapting to climate change hazards is one of the foremost challenges facing Pacific Island Countries and

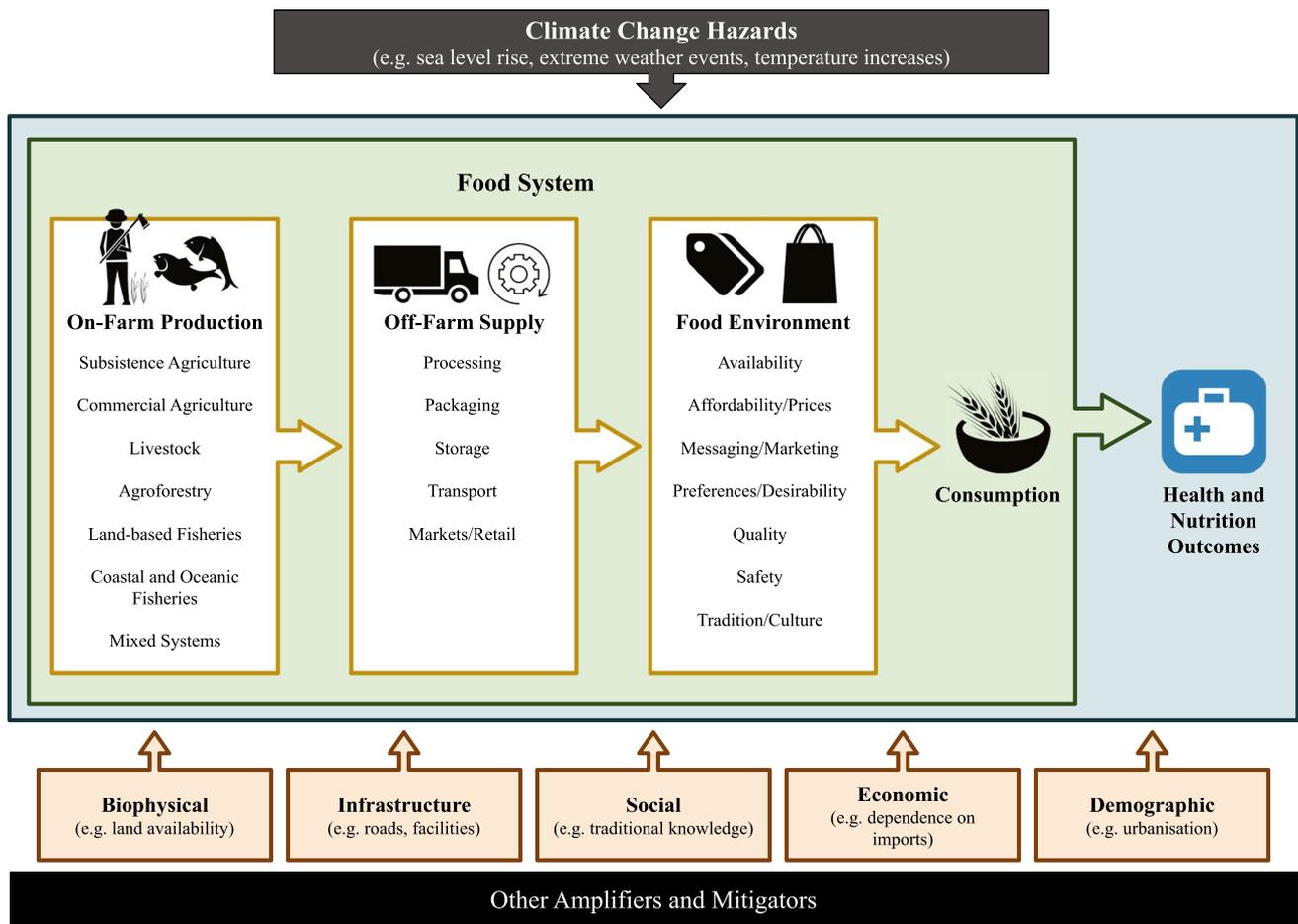


Fig. 1 Conceptual figure of food systems components, climate change hazards, and potential amplifiers and mitigators of climate change impacts on the system. The figure demonstrates the different components of the conceptualised food system including On-Farm Pro-

duction, Off-Farm Supply, and Food Environment, and how these are dependent on inputs including Biophysical, Infrastructure, Social, Economic, and Demographic inputs. Figure inspired by conceptualisations in Mbow et al. (2019) and Turner et al. (2018)

Territories (PICTs), which are particularly vulnerable to the adverse effects of climate change. PICTs are increasingly affected by sea-level rise, changing rainfall and temperature patterns, floods, drought, and storms (Mycoo et al. 2021). This systematic review is focused on the Pacific region due to increasing foreign policy priorities and points of engagement in the Pacific on climate change. In rural areas, the heavy reliance on subsistence and cash crop agriculture and fisheries for livelihoods make PICTs vulnerable to climate hazards. In urban areas, rapid urbanisation and population growth, alongside an increasing dependence on food imports, are also contributing to heightened food stress in many PICTs (Pacific Community 2021). PICTs have become vocal leaders in climate adaptation out of necessity, demanding and shaping national and regional climate policies and the Paris Agreement, and leading the way on adaptation in small island developing states (McLeod et al. 2019). Yet, to effectively finance and support climate adaptation and food systems resilience efforts in the Pacific, we need to understand the current evidence to inform those efforts and research gaps to fill.

Methods

To facilitate the growing efforts to understand and address climate change threats to food security in PICTs, this study takes a systematic approach to canvassing the current state of research on climate change impacts on different components of food systems in PICTs within the grey and peer-reviewed literature. Specifically, we ask:

1. What does the published scholarship tell us about the impacts that climate change hazards are having or will have on Pacific Island food systems?
2. How frequently are food systems approaches reflected in the current climate change and food security scholarship within the PICTs?
3. What gaps in research and scientific knowledge remain to be filled to better inform climate change decision-making and adaptation planning to ensure food security in PICTs?

Ultimately, this review collates information in a way that can inform decision-making about research investments on climate impacts and adaptation in the region.

Geographic scope

This review covers all 21 Pacific Island Countries and Territories (PICTs) that are members of the Pacific Community. These are American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis & Futuna (Fig. 2). Studies that included multiple countries or took a regional perspective are also included.

Search strategy and inclusion criteria

This study followed a systematic literature review process, using a modified Preferred Reporting Items for Systematic

Reviews and Meta-Analyses (PRISMA) approach (Moher 2009) to ensure the inclusion of grey literature. PRISMA offers a robust review process and checklist, which minimises the risks of overlooking relevant evidence and improves the reproducibility. A set of keyword strings capturing different aspects of the food system was developed and used to identify relevant sources of information. Searches were conducted between February and April 2022. Different keyword search strings were used for food production, physical off-farm activities, and food environments, on Google Scholar, Google Web, and the Web of Science database (see Supplemental Materials Table S1). For production, the terms included were (Climate change) AND (agroforest* OR agricultur* OR fisher* OR livestock OR food produc*). For physical off-farm activities, the following terms were used: (Climate change) AND (food AND (process* OR packag* OR transport* OR retail* OR market)). Food environment was captured through the terms (Climate change) AND (food NEAR (demand OR consum* OR afford* OR access* OR prefer* OR nutrition*)). All searches included a “Pacific Island*” term.

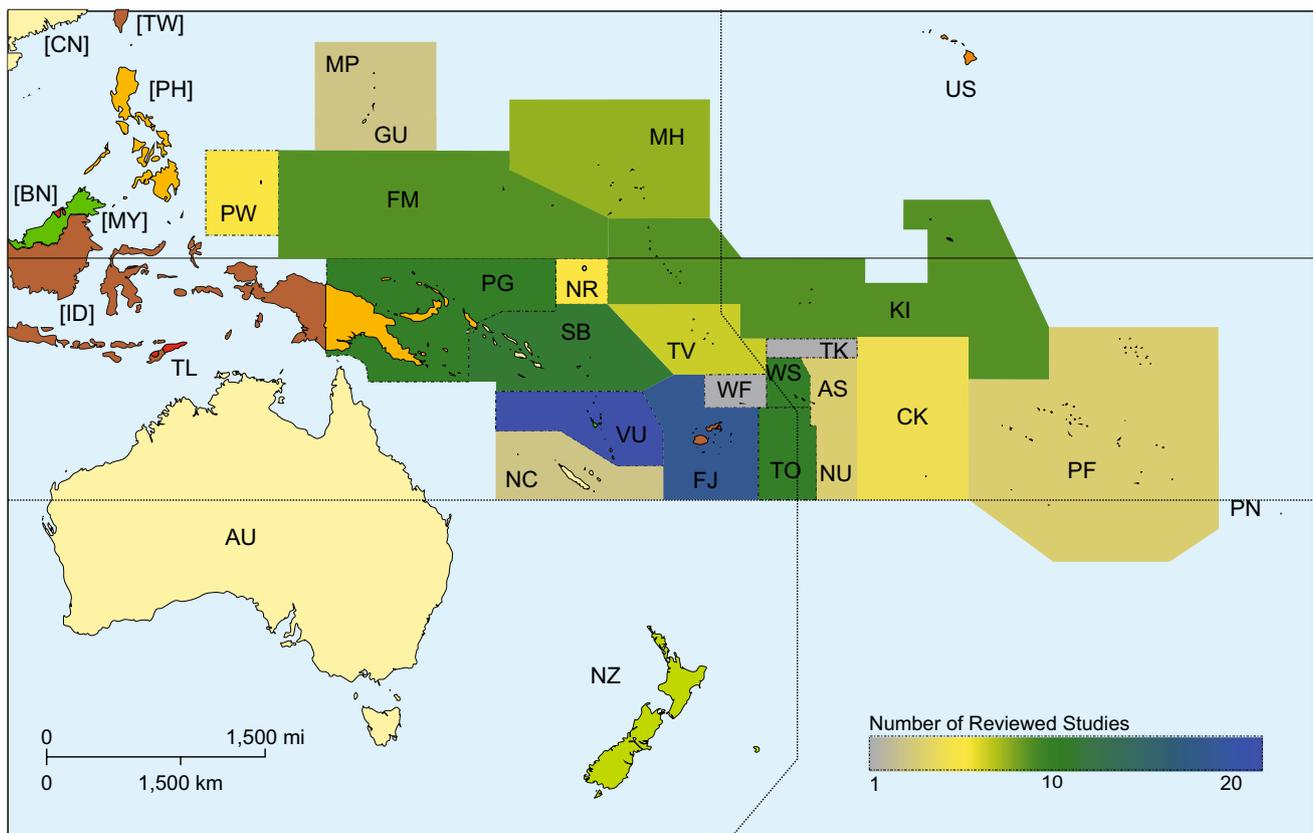


Fig. 2 Map of the 21 member Pacific Island Countries and Territories, coloured based on their representation in reviewed studies. Vanuatu (VU)—22; Fiji (FJ)—18; Solomon Islands (SB)—11; Papua New Guinea (PG)—10; Samoa (WS)—10; Tonga (TO)—10; Federated States of Micronesia (FM)—9; Kiribati (KI)—9; Marshall Islands (MH)—8; Tuvalu (TV)—7; Nauru (NR)—6; Palau (PW)—6;

Cook Islands (CK)—4; American Samoa (AS)—3; French Polynesia (PF)—3; Niue (NU)—3; Guam (GU)—2; New Caledonia (NC)—2; Northern Mariana Islands (MP)—2; Wallis & Fortuna (WF)—1; Tokelau (TK)—1. There were 41 studies that examined the PICTs at regional level. Figure modified from Reis (2006)

For Google Scholar searches, results were ordered by relevance and the first 200 search results were considered, after test searches showed that no additional relevant studies were found after the first 100 results. The Web of Knowledge database and Google Web searches yielded fewer results, so all were considered. The publications pages on the websites of the Secretariat of the Pacific Community (SPC), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), The United Nations Food and Agriculture Organisation (FAO), and the Climate Change, Agriculture, and Food Security (CCAFS) Research Programme of the CGIAR were manually searched to identify any technical reports not captured in the web and database searches. No new results were identified from the latter two organisations. World Bank Climate Risk country profiles for the available Pacific Islands were identified during the expert consultations with the Secretariat of the Pacific Community (SPC) and the Department of Foreign Affairs and Trade (DFAT), held to refine the review approach. Both peer-reviewed studies and grey literature (e.g. working papers, institutional reports) were included if published from 2010 to the time of the search. The timeframe of 2010–2022 was chosen due to the rapidly changing nature of climate change and our understanding of its impacts, suggesting that earlier studies would be less relevant to understanding the current and future impacts.

Results of the keyword searches were first screened at the abstract and title levels, and duplicates and any pure review papers were removed (Fig. 3). Then, the full-texts of remaining results were screened to ensure they met a set of inclusion criteria, and allocated a numerical ID. Documents were included in the study if they met the following criteria:

1. Includes examination or analysis of one or more climate change impact (and not only mentioned as background information)
2. Includes examination or analysis of one or more component of the food system
3. Includes specific results in at least one Pacific Island Country or Territory
4. Provides specific results and/or conclusions that could inform decision-making

Data extraction and analysis

The full-text results of the screening process were reviewed against a standard coding framework, which identified the climate hazards and impacts on different aspects of the food system (Supplemental Materials Table S2). The thematic coding frame was constructed based on the food systems conceptual framework presented earlier, the findings about adaptation strategies in a previous review of food systems resilience in the Indo-Pacific (Friedman et al. 2022), and in consultation with stakeholders from SPC and DFAT, to ensure all desired information was captured.

During the data extraction, we reviewed the included documents using the coding framework. The timescale, methods, geographic scope, and organisations involved in the study were noted. It was also noted if the study focused on a particular component of the food system, or took a systems approach. In the review, studies were considered taking a systems approach if they analysed at least two of the three broad food system components (on-farm production, off-farm supply, and food environment). We documented the climate hazards and impacts on food system components for each study. Climate hazards and impacts were only included in the data extraction if the study assessed them in relation to the food system, and not as general background. Impacts were documented for each of the three broad food system components. Any proffered adaptation strategies were also noted; however, it is important to note that adaptation-focused studies were not targeted in the search strategy, rather this review focused on studies that discussed specific climate impacts on food systems.

To address the first question about the state of the published literature, we produced descriptive summaries of the climate change hazards and impacts for particular food system components. Summarising the background information extracted from studies also provided an overview of the existing research landscape. For the second question on the frequency of systems approaches, we cross-tabulated the occurrence of studies that looked at both on-farm production and food environment (there were very few off-farm supply studies). We also summarised the climate change impacts of only studies that met our criteria for taking a systems approach. Finally, to comment on the gaps in research and knowledge, we qualitatively considered the results of the analyses in relation to the food systems conceptual framing and geography of the region. Data was analysed using R Studio (R Core Team 2021), and visualised using the “ggplot2” package (Wickham 2016).

Results

General overview of the state of knowledge

We identified 104 studies as examining the impacts of climate change on food systems in PICTs, of which 53 were grey literature and 51 were peer-reviewed articles. Over one-third of these studies were from 2020 onward (42%, $n = 44$), and fewer than one-quarter were prior to 2016 (21%, $n = 23$). Of the 104 studies, a majority of sources used synthesis methods (69%, $n = 72$), while less frequently employed methods were ethnography or interviews (20%, $n = 21$), other models (15%, $n = 16$), surveys (12%, $n = 13$), climate forecasts (14%, $n = 15$), and field experiments (2%, $n = 2$) (Fig. 4). The majority of these sources were qualitative: 61% of sources contained qualitative biophysical data ($n = 63$) and 57% of sources contained qualitative social data

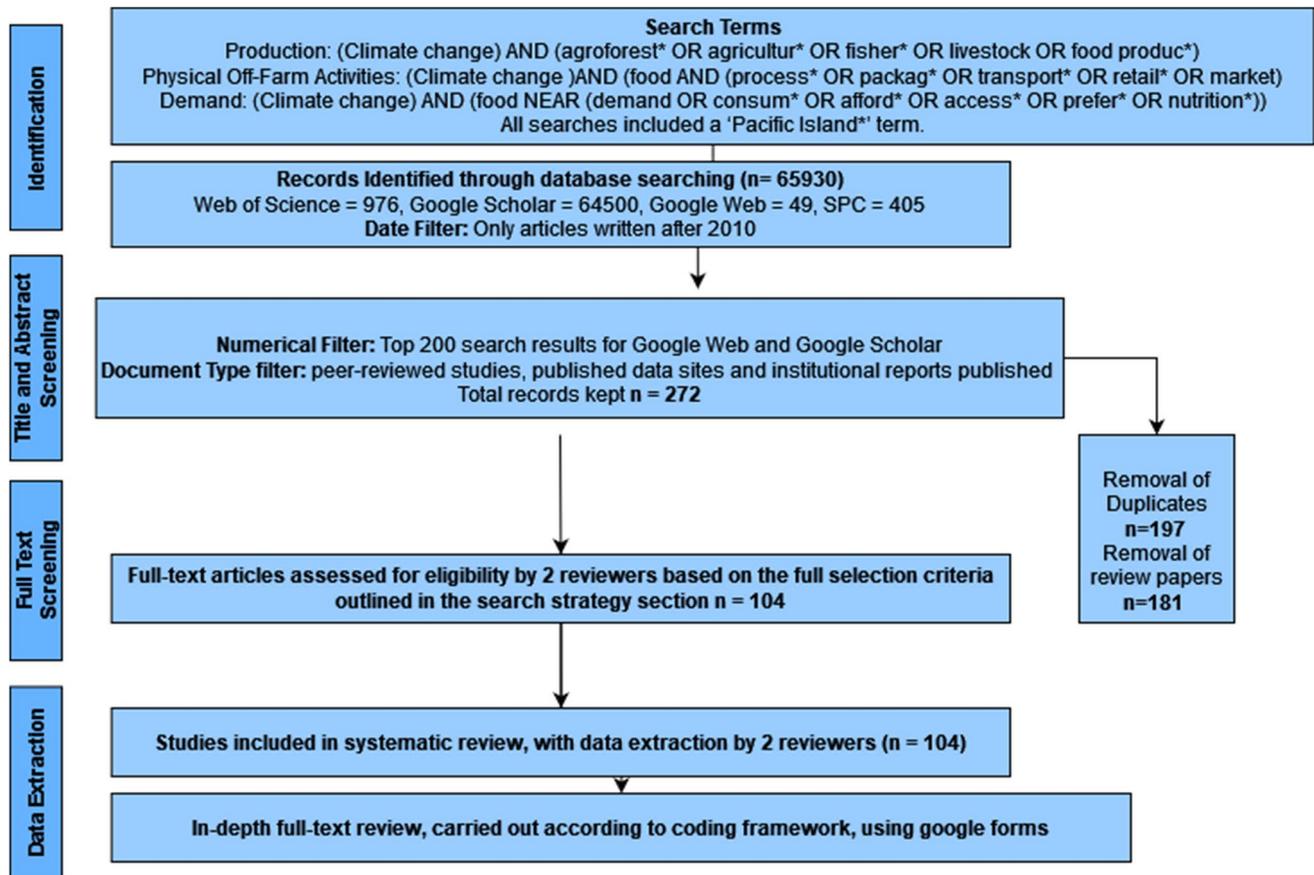


Fig. 3 Process employed for determining relevant literature to include in the review. The process began with “Identification” of all possible literature through a comprehensive keyword search. A “Title and Abstract Screening” applied inclusion criteria 1–3 to determine whether full texts should be examined. Duplicates and pure review

papers were removed at this stage. At the “Full Text Screening”, articles were further assessed for eligibility against all four inclusion criteria. Papers were then reviewed according to a coding framework (Supplemental Material Table S2) in the “Data Extraction” stage. A total of 104 documents were ultimately reviewed

($n=59$). Quantitative biophysical data was found in only 20% of sources ($n=21$), and quantitative social data was found in 10% of sources ($n=10$). This general overview of the reviewed studies demonstrates a pronounced need for more empirical research, particularly quantitative social and natural scientific studies using diverse or mixed methods.

Geographic distribution

Studies were not evenly spread across PICTs (Fig. 2). A large proportion of research took a regional perspective, covering PICTs generally (39%, $n=41$), with fewer focusing on specific countries or territories. Some studies addressed climate change impacts on food systems in PICTs generally, but included case studies in specific countries to illustrate particular examples or events. Vanuatu (21%, $n=22$), Fiji (17%, $n=18$), and the Solomon Islands (11%, $n=11$) were the top three most included locations aside from the region as a whole. Of note, these three countries are in Melanesia.

The most prominent Polynesian countries are Samoa and Tonga ($n=10$ each). The Federated States of Micronesia and Kiribati are the best represented Micronesian countries ($n=9$ each). Overall, the research landscape tends to favour regional studies or those situated in the larger Melanesian islands, despite a need for more granular research driven by the diversity across the Pacific Islands. The full list of studies and their geographic provenance is included in the Supplemental Materials (Table S3).

Overview of climate change hazards and food systems impacts

Projections of climate change highlight the vulnerability of island nations to climate hazards, and the urgency of addressing adaptation (Mycoo et al. 2021). Sea-level rise, extreme precipitation events, and cyclones and storm surges are the biggest concerns, but temperature rises and ocean acidification also pose risks. The main climate

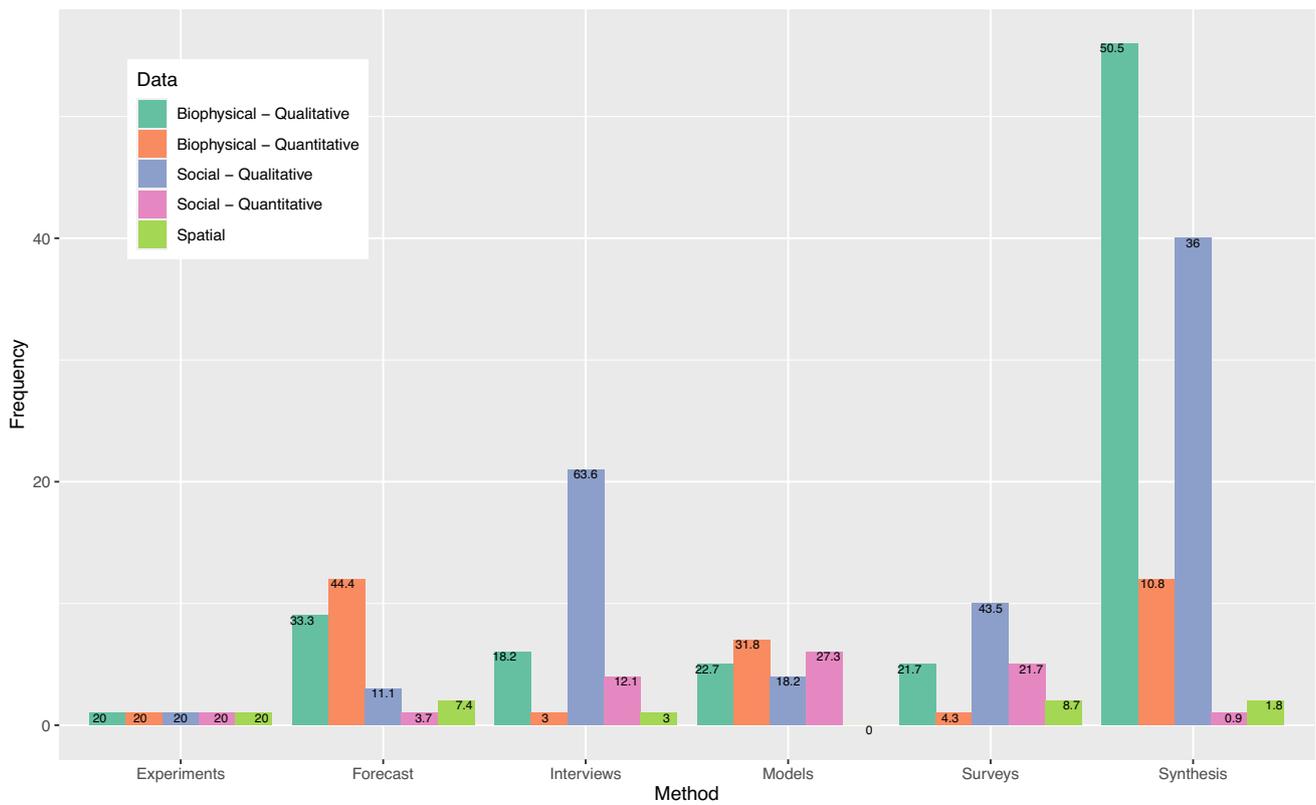


Fig. 4 Frequency of methods applied in studies and the type of information presented. Colours reflect whether the data was biophysical, social, or spatial, and qualitative or quantitative. Cumulative fre-

quency may be greater than 104, as studies could apply more than one method or produce multiple types of data. Values on the bars are percent representation of each data type per method

change hazards addressed in relation to food systems in the reviewed studies were storms and extreme weather events (79.0%, $n = 82$), temperature-related hazards (72%, $n = 75$), precipitation events (70%, $n = 73$), and sea-level rise (68%, $n = 71$). Most studies looked at past events (retrospective) or timelines of post-2030 (usually 2050 to 2100), rather than the nearer-term 5–10 years. About one-quarter (27%, $n = 28$) did not specify the time scale of climate hazards examined. While the extent of impacts of climate change are likely to differ between island types (e.g. coral atolls, volcanic, continental) and urban or rural areas, the climate hazards Pacific Islands are exposed to seem to be relatively consistent across studies, and reflect the primary climate projections for the region.

On-farm domestic food production was the most frequently studied food system component (66%, $n = 69$). The most often addressed production components were subsistence agriculture (75%, $n = 78$), followed by coastal and oceanic fisheries (66%, $n = 69$), commercial agriculture (37%, $n = 38$), and land based fisheries (15%, $n = 16$). Agroforestry and livestock were the least frequently addressed (5%, $n = 5$), along with other mixed systems (2%, $n = 2$). The most prominent climate impact on food production was reduction in growth and/or

catch (73%, $n = 76$). Loss of land and natural habitat (53%, $n = 55$), saltwater incursion (47%, $n = 49$), crop destruction or failure (39%, $n = 41$), shifts in range and/or distribution (37%, $n = 38$), and pests and diseases (35%, $n = 36$) were also relatively common (Fig. 5, top). This fits with the relative power and importance of the agriculture and fisheries sectors in the region, and the tendency for aid funding and commercial investment to support production research and development. Nevertheless, the prominence of qualitative, synthetic studies suggests that there is still a need for more specific and nuanced quantitative research on food production.

Off-farm components were under-represented as a sole focus in reviewed studies (6%, $n = 6$). However, studies that took a systems approach would also have considered some of these components. Furthermore, some studies that focused on production systems still mentioned an off-farm implication. Nutrition, which was conceptualised as an outcome in the framework, was the most frequently addressed off-farm component (38%, $n = 40$), with many studies making the link between increased dependency on nutritionally low, imported foods and climate change impacts. Social and cultural aspects were also often represented (28%, $n = 29$), followed by markets (14%, $n = 15$), and transport (14%, $n = 15$).

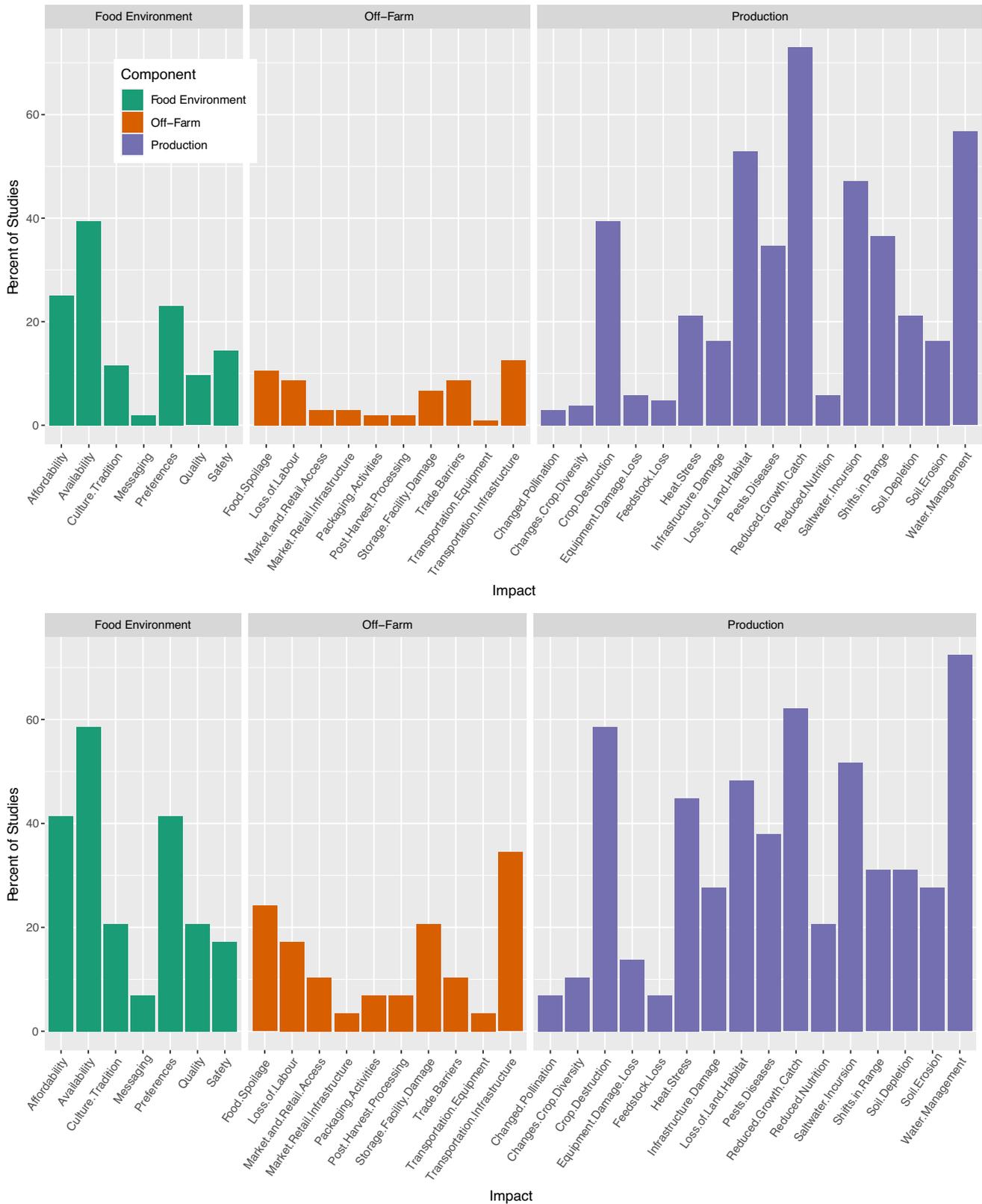


Fig. 5 Summary of the climate change impacts arranged by food systems components. (Top) Summary of climate change impacts for all studies reviewed. Food production impacts are the best represented, with fewer analyses of other food system impacts. Bars are repre-

sented as a percentage of all studies ($n=104$). (Bottom) Summary of climate change impacts only for studies that adopted a systems approach. Bars are percent of total systems-oriented studies ($n=29$)

Off-farm impacts were divided into physical impacts and food environment impacts. Although under-represented, the most commonly addressed off-farm physical climate impacts were transportation infrastructure damage or obstruction (13%, $n = 13$) and food spoilage (11%, $n = 11$) (Fig. 5, top).

Because food environments were expected to comprise the inter-related personal and environmental factors that influence people’s food behaviours and nutritional status (Turner et al. 2018), we would expect to see some overlap between topics of food production and food access and consumption. As such, studies that examined nutrition outcomes ($n = 40$) often made the connection with aspects of food environments, such as food availability (70%, $n = 28$), preferences (50%, $n = 20$), and affordability (40%, $n = 16$). In this review, impacts of climate change on food availability were discussed in 39% of studies ($n = 41$), while impacts on affordability (25%, $n = 26$) and preferences (23%, $n = 24$) came up in roughly one-quarter of studies. While not as frequent, the impacts of climate change on food safety (14%, $n = 15$) and culture or tradition (12%, $n = 12$) are incredibly important and understudied.

There was also some recognition of the interconnectedness of food production and consumption through the studies that addressed both food production and food environment

impacts from climate change (Fig. 6). Of the most prominent food environment impacts, the connection between reduced yield or catch and food availability was strongest (76% of studies on availability, $n = 31$). Affordability was discussed in tandem with reduced yield or catch, but also with issues of water management, pests and disease, and crop destruction from storms and heat (57–62%). Two-thirds of studies discussing food safety or culture and traditions also examined yield or catch reductions and loss of land or habitat. These figures suggest that studies on food environments lean themselves to systems approaches, making connections between two or more aspects of a food system.

Over one-quarter (28%, $n = 29$) of documents took a systems approach to assessing climate change impacts. Studies adopting a systems approach considered a more even distribution of impacts across components, with both food environment and off-farm physical impacts showing up in a greater proportion of studies (Fig. 5, bottom). Food environment impacts were more prevalent and off-farm impacts of storage facility damage rose in importance. Production impacts were still the most common, but the relative prevalence of some production impacts also shifted when only looking at systems studies. For instance, water management, salt water incursion, and crop destruction rose in importance

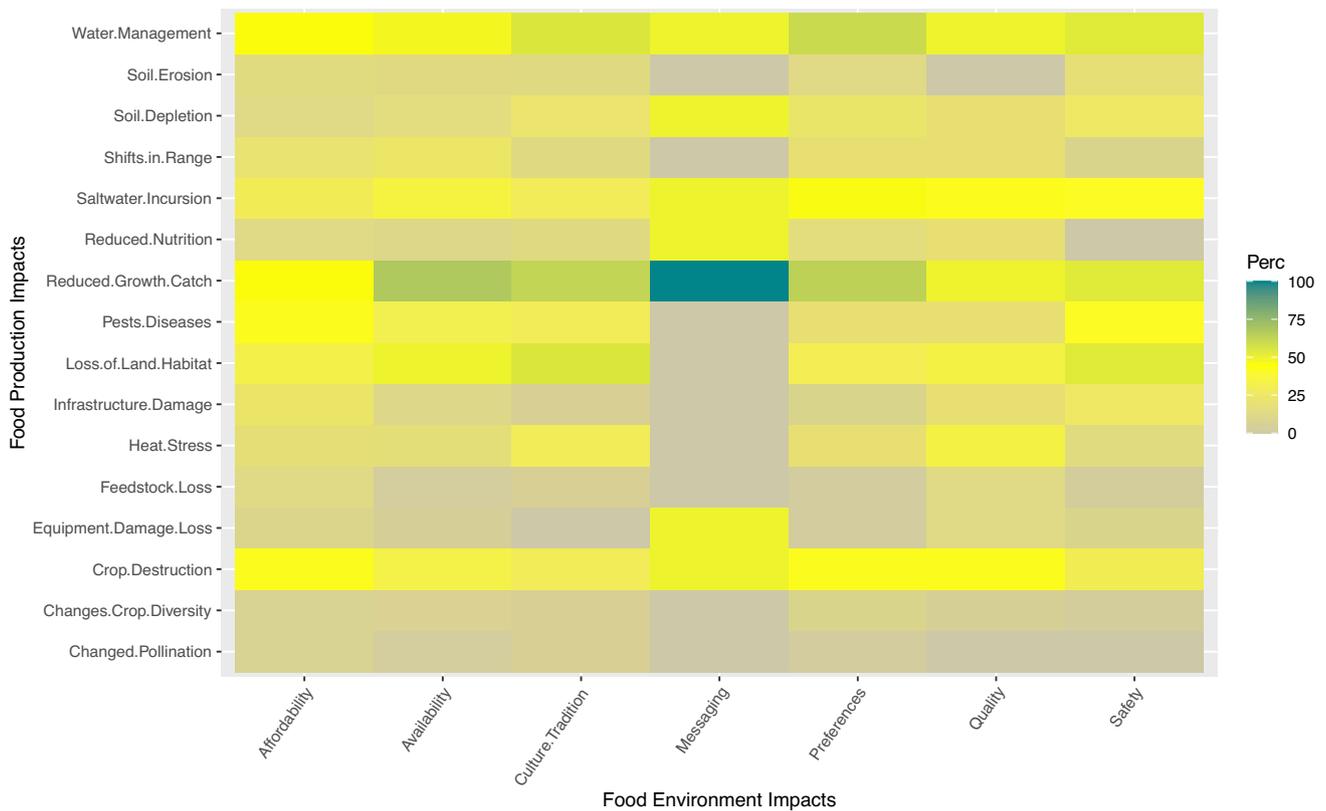


Fig. 6 Heat map of studies discussing both food production and food environment impacts. Colour is based on percent representation by column. Total may be over 100%, as studies could include multiple impacts

compared to the dominance of reduced growth/catch in the review as a whole. This shift could hint at a more holistic view of the production environment present in systems studies.

Adaptation strategies

The focus of this review was not on adaptation strategies; however, these were noted in relation to the climate change impacts assessed in the reviewed literature. Education and awareness was the adaptation solution most commonly offered in the context of food systems and climate change (43%, $n=45$), and includes but is not limited to: capacity building and training, early warning systems, and information and advisory services like extension. Sustainable practices were also explored in over one-third of studies (38%, $n=40$), covering a wide range of solutions such as organic/ethical farming, soil management practices, and sustainable harvesting of marine resources. Coordination of policies and high-level decision-making (33%, $n=34$), further research and development (27%, $n=28$), and resilient crops and breeds (28%, $n=29$) were also commonly mentioned as possible adaptation solutions (Fig. 7).

Discussion

This review aimed to understand the state of research examining climate change impacts on food systems in PICTs, and assess the extent to which this research adopts a systems approach. The review highlighted the dominance of production-focused research, despite the emerging importance of interdisciplinary research and systems approaches. The value of systems approaches to food and nutrition security has been widely touted in the conceptual literature, yet was only moderately represented in the review. The results highlighted implications and future research directions in the area of climate change and food systems, with insight into potential adaptation measures. Finally, there was a paucity of food systems research at national and sub-national scales, as well as from non-Melanesian countries, which is a critical gap when trying to understand the complex interactions between climate change and food systems components from local perspectives. This discussion elaborates on the value of a systems approach to food security, which is under-represented in the climate change research in PICTs, and uses examples from reviewed studies to illustrate best practices to take the research forward.

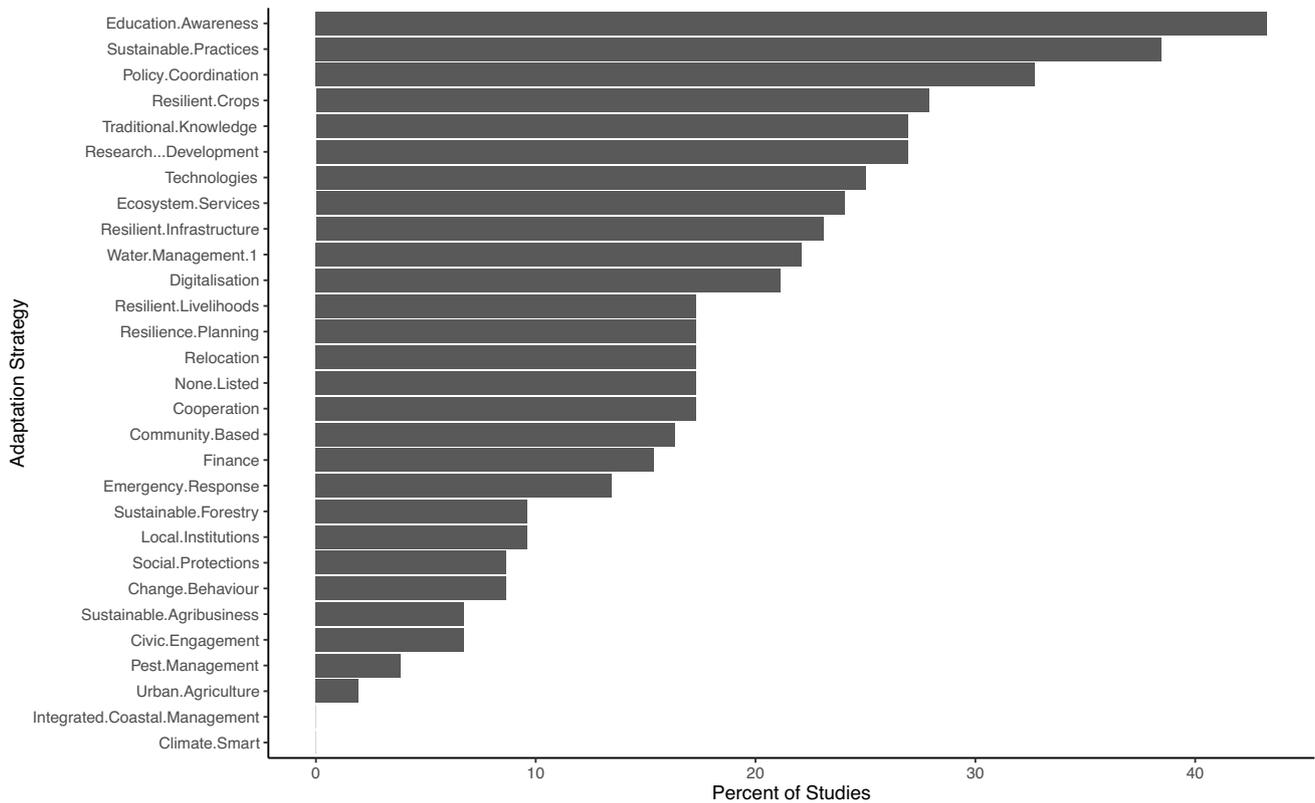


Fig. 7 General categories of adaptation strategies, organised in reverse order by proportion of total studies. Cumulative percentage is greater than 100, because reviewed studies may have mentioned more than one adaptation strategy

The value of systems approaches to food security

The results of this review showed the dominance of research in PICTs on climate change and food production, with non-production components and systems approaches to food security under-represented in the literature. Such a limited focus risks overlooking the complex interactions between socio-economic and physical elements, and simplifying our understanding of food system vulnerability. Systems approaches allow us to visualise and understand the underlying complexity of food system dynamics, and how factors such as food production, processing, availability, and consumption interact with other socio-economic elements (Borman et al. 2022). In a research context, a systems approach could bring attention to how changes in dominant food production components have knock-on consequences for other aspects of the system, such as people's livelihoods, a population's capacity to adapt, and resilience to shocks overall. Reviewed studies that took systems approaches emphasised the value of embracing complexity, linking components that are often siloed in practice, and making connections between often segregated but inherently interdependent fields like health and nutrition.

Systems approaches within this review demonstrated the importance of conceptualising food systems as complex systems in which social, cultural, and economic factors are linked to the physical food system. One article, Currenti et al. (2019), used a systems approach in their case study of Nawairiku, Fiji, to highlight the vulnerabilities within the food system as complex interactions between climatic and non-climatic stressors. Building materials used to construct and improve infrastructure for food production and transport were identified as a crucial component of the food system, and adaptation strategies that failed to consider the dependence on such inputs were shown to have limited success. Using this type of systems approach, the study identified that effective adaptation solutions must consider more than just the physical components of the food system, acknowledging how connected environmental, social, and economic factors are within local contexts (Currenti et al. 2019). For example, an adaptation strategy aimed increasing food systems resilience through more adaptive infrastructure would need to address not only accessibility of materials, but also provide concurrent education on building and maintenance.

Systems approaches enable making important connections between often siloed fields, like food security, human health, and the environment. Another study from the review, Conn et al. (2020), illustrated the importance of envisioning health and nutrition as part of the food system in order to build resilience. Exploring the linkages between local food production and non-communicable diseases, the study demonstrated how underdeveloped infrastructure and climate hazards erode local

agricultural production and associated food security, thus leading to a reliance on imported and nutritionally poor food (Conn et al. 2020). The authors concluded that multi-sectoral adaptation strategies and policies that incentivise healthy food choices by increasing the availability of locally produced food, while addressing sustainable farming practices and trade, contributed to increased resilience across the system in the face of climate change. Education and government support and subsidies for local producers were put forward as strategies to increase the availability of locally produced food and incentivise healthy dietary choices. The authors also argued that increasing demand for locally sourced food, and moving away from a reliance on imported food, could contribute to shifting the focus onto regional economies, improving local livelihoods and increasing the resilience of local food security.

The "One Health" concept takes a similar systems approach as the previous study to human health, with a strong focus on the interactions between humans, environmental factors (e.g. ecosystems, climate change, pollution), and disease (Xie et al. 2017). While the impetus for the growing interest in One Health approaches can be attributed to emergence of zoonotic diseases and a recognition of the interactions between ecology and human welfare (Mackenzie and Jeggo 2019), the general rationale for applying systems thinking to achieve human health or food security and nutrition outcomes is consistent. Researchers have previously outlined the intersection of One Health and Food Security, pointing to the role of polluted water in food safety and transmission of food-borne pathogens, or disasters in livestock diseases and escalating food prices (Garcia et al. 2020). In the context of the Pacific Island Countries and Territories, where populations are exposed to extreme events and have limited freshwater supplies, these integrated systems approaches are critical to fully comprehending food and nutritional security outcomes, and the factors driving them.

Successful adaptation with local engagement and a systems approach

Adaptation strategies are a product of our understanding of food systems vulnerabilities and impacts, so taking a limited view might result in sub-optimal adaptation for food security. Studies from the review that took a systems approach generally discussed adaptation strategies that not only addressed food production, but aimed to strengthen multiple socio-economic and cultural elements of the food system. Dutra et al. (2021) acknowledged interactions between climatic and non-climatic drivers that contributed to general coral reef health in the Pacific and the subsequent food production dependent on reef ecosystems. By acknowledging the system in a holistic sense, the study was able to recommend transformative adaptation strategies that could contribute to both positive social and ecological outcomes and to long-term resilience

across the local social-ecological system (Dutra et al. 2021). These strategies included re-implementing traditional coral reef management techniques, shifting social norms around local exploitation, and improving governance of coral reef systems, while paying attention to the development aspirations of the community.

The failure to consider social and ecological interactions within a food system could lead to adaptation strategies that are unsuccessful or that create unintended vulnerabilities in the system. For example, in a case study in Fiji, by not accounting for social and cultural components of drought responses and instead instituting a government-designed solution, the adaptation solution ended up not functioning effectively (Pearce et al. 2018). The drilling of new boreholes in Vusama village by the Fijian government was shown to have adverse consequences for existing local practices. This adaptation strategy was intended to provide access to clean and safe water for consumption and growing crops as a back-up measure during prolonged drought, but actually resulted in the neglect of wells on which villagers normally rely (Pearce et al. 2018). The authors concluded that any adaptation interventions needed to be developed with local communities to instil ownership over projects and ensure they reflect the current constraints and practices of communities. Besides local relevance and motivation, another determinant of adaptation intervention success is the longevity of funding—in essence, externally funded projects often end when the funding or grant is over and there is not enough financial and technical capacity within communities to continue the project (McLeod et al. 2019). Limited technical capacity for monitoring and management is also often a barrier to adaptation, and building this capacity can enable more locally run adaptation projects in the future.

Geographic and methodological limitations

PICTs are extremely diverse in culture and context (Gero et al. 2013), and examining food systems impacts at a broad geographic scale may overlook this diversity. National and sub-regional perspectives were under-represented in the review, and most of those studies concentrated in Melanesia. There was particular oversight of smaller atoll islands, such as The Federated States of Micronesia, Marshall Islands, and Tuvalu. The countries and territories in the South Pacific not only vary substantially by size of land mass and population, but also stage of economic development. This heterogeneity of socio-cultural, economic, and biophysical contexts may result in different levels of vulnerability and disaster risk management capacity, and also mean that successful adaptation strategies in one context may not scale out to other Pacific Islands (Butler et al. 2020; Gero et al. 2013). A renewed focus on country and sub-region specific research would allow for greater assessment of climate change risks to food systems,

which could translate into adaptation strategies that are better suited to local contexts. Due to the cultural, socio-economic, and geographic diversity of the region, studies have argued that adaptation strategies should address the particularities of where they will be implemented to be effective (Butler et al. 2020; Pearce et al. 2018).

One study in this review analysed priority adaptation actions for Papua New Guinea, and the importance of local context in determining adaptation success (Butler et al. 2020). In this study, adaptation strategies, although shown to be effective in other case studies and developed using systems-based planning processes, were not necessarily effective when scaled out to different locations (Butler et al. 2020). These failures were underpinned by assumptions that agricultural practices, natural resource use regimes, and climate hazards would be similar across geographies and therefore would require similar adaptation measures. This example demonstrates how developing standardised adaptation strategies for broad-scale application across regions is a challenge, and emphasises the need for local contextual information to accommodate the diversity of communities across the Pacific Island region. Ultimately, strategies based on this scaled-down understanding are more likely to reflect individual food systems complexities and subsequently meet with more success in adaptation. As such, more national and sub-national research on climate change impacts would enable a better understanding of the food systems adaptation options that could best address context-specific challenges.

Limitations and future directions

This review had several limitations. For one, the large proportion of synthesis studies limited the extent of novel data under review and consequently affect our conclusions about how food systems approaches are applied in empirical climate change studies. Similarly, while this review identified that credible scientific information is available and has been increasing rapidly since 2020, there was a strong bias towards qualitative data. This data shortcoming could prevent or impede adequately informed risk management, adaptation planning, and associated decision-making for food systems-related sectors, including health, infrastructure, water, energy, tourism, food production (fisheries, agriculture), and natural resources (forestry, biodiversity). More studies generating quantitative data could provide an improved understanding of the scale of the challenge and the capacity required to adapt. In tandem with qualitative data, such as information about cultural connections to food and place, quantitative research could lend itself to more consistent decision-making and better-informed policy setting and adaptation planning.

Another limitation stems from the search terms focussing on impacts, rather than adaptation. As such, there were limited conclusions that could be made about specific strategies

to address climate change impacts. Considering how intertwined climate impacts and adaptation are, it would be prudent for future studies to include consideration for both. Future research could also seek to verify our observation that adaptation strategies lacked robust evaluation in the food systems literature across PICTs, generally defaulting to an aspirational list of recommendations for decision-makers. As with any review, this study may not have been exhaustive and thus may have under-represented some themes. For instance, general studies on infrastructure or trade were out of the scope of our review. These sectors still have implications for the movement and consumption of food products, but the studies may not have implicated food security or food systems-related sectors. Finally, casting a wider net in terms of databases and organisational websites to search could have yielded additional studies to review.

Conclusion

This systematic review aimed to assess the state of research on climate change impacts on food systems in PICTs, filling an important gap in knowledge of climate change vulnerability to inform decision-making in the region. While there are publications that provide overviews of climate change impacts on agriculture, fisheries, or general food security in the Pacific, this review provides a critical baseline of our understanding from a whole systems perspective. We found that a large proportion of the literature addressed only the food production components of the food system, failing to consider the complex interactions between biophysical and socio-economic dimensions that are integral to functional food systems. This represents an opportunity to prioritise empirical research in the region that is actively designed around the interlinkages and interactions between components of food systems, specifically under projected climate conditions and stresses. In essence, the well-developed food systems conceptual frameworks could be better applied to empirical research moving forward.

The geographic shortcomings found in this review highlight further need for more investment in research focused on the sub-regional, national, and sub-national levels. While some policy decisions and coordination occur at the South Pacific regional level, downscaled evidence is critical to inform national policy formulation and implementation within a country. Finally, the type of evidence currently available, and lack of integration across food systems components, has implications for developing viable climate adaptation strategies to maintain Pacific food security. The examples provided in this review demonstrated the value of developing adaptation strategies that consider both food production and consumption, as well as the biophysical and socio-economic

components of the food system, illustrating the risks of not accounting for such complexity. Future research could better integrate climate impact assessment and adaptation evaluation within food systems in PICTs. Ultimately, there is leadership and motivation in Pacific Island Countries and Territories to take meaningful steps in building food secure and climate resilient communities. To ensure the best evidence underpins the decisions and actions toward this outcome, this review underscores not only the need for more research investment, but also for that research to better integrate across food system components. We showed the growth in the research in this space over the last decade; now we need to direct it in ways that most effectively benefit food security and food systems resilience in the face of climate change.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10113-023-02040-3>.

Acknowledgements This study was carried out as part of the Resilience Initiative for Food and Agriculture (RIFA), a partnership between the Australian National University, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Australian Department of Foreign Affairs and Trade (DFAT). The authors would like to thank the staff from the Secretariat of the Pacific Community (SPC) for consulting on the coding framework that guided the data extraction in this study, to ensure its fit-for-purpose.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. The authors would like to acknowledge funding from the Australian Department of Foreign Affairs and Trade (DFAT).

Data Availability The data and R code used for the analysis in this study are available on the Open Science Framework: <https://osf.io/c48hd/>.

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