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Designing Climate Information Services to Enhance Resilient Farming Activities: Lessons From Papua New Guinea

Rachel S. Friedman[1]*, Ellis Mackenzie[2], Ruth Baiga[3], Kasis Inape[4], Steven J. Crimp[1,5†] and Mark Howden[1†]

[1] Institute for Climate, Energy, and Disaster Solutions, College of Science, The Australian National University, Acton, ACT, Australia, [2] Sustineo Pty Ltd., Canberra, ACT, Australia, [3] Momase Regional Centre, National Agricultural Research Institute of Papua New Guinea, Bubia, Papua New Guinea, [4] Climate and Special Services Division, PNG National Weather Service, Boroko, Papua New Guinea, [5] Fenner School of Environment and Society, The Australian National University, Acton, ACT, Australia

Anthropogenically-driven changes in seasonal climate patterns are already jeopardizing traditional farming practices all around the world. These climatic changes increasingly expose farmers to challenging conditions, reducing the efficacy of existing farm practices and productivity. There is a plethora of information, tools, and practices that could be useful for farmers trying to respond to climate variability and change, including climate projections, horticultural advances, and agricultural management best practices. Whilst these tools and knowledge exist, they are often not contextualized in ways that equitably facilitate decision-making and action. To ensure weather and climate information services are accessible and useful to farmers, it is critical to understand and integrate considerations for the desired types, timing, and uses of the information. The one-size-fits-all information services that are often available don't account for regional or social differences, local physical conditions, or the needs of different populations. In order to improve our understanding of how weather and climate information services can better cater to farmers' needs when modifying and adapting their goals, risk management, and farm practices, we carried out a household survey in communities across three provinces in Papua New Guinea. The survey was developed to draw out key design considerations for seasonal climate forecasts in terms of timing, type of information, and applications. Based on the clustering and associations of these variables, this study identifies different profiles of information services content. It then examines whether specific profiles are associated with demographic groups or geographic locations. The findings demonstrate gender and geographic differences in the desired bundles of weather and climate information, and therefore can help to pinpoint specific components that would be beneficial to incorporate into extension and outreach programmes in different contexts within Papua New Guinea. This study highlights the value of tailoring weather and climate information services with specific groups of farmers, thereby enabling more equitable access to and use of critical knowledge for smallholders to build the capacity, knowledge, and systems to strategically adapt to climate change. At the same time, this study illustrates areas to gain efficiency and potentially scale up the provision of climate information services.

Keywords: climate information services, Papua New Guinea, smallholder farming, gender, cluster analysis

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***Correspondence:**
Rachel S. Friedman
rachel.friedman@anu.edu.au

† These authors share senior authorship

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INTRODUCTION

The Climate Challenge for Agriculture

Island nations are expected to be increasingly and severely vulnerable to adverse impacts of climate change (Mycoo et al., 2021). The residents of Pacific Island nations are likely to face particularly detrimental effects from climate change, including major impacts related to sea level rise and shifts in rainfall leading to freshwater challenges (Nurse et al., 2014). The Sixth Assessment report of the Intergovernmental Panel on Climate Change (IPCC) found that the Pacific will experience increasingly extreme weather, in terms of elevated temperatures, periods of heavy rainfall, flooding, and drought, and progressively more intense tropical cyclones (Ranasinghe et al., 2021).

Communities reliant on agriculture-based livelihood systems have been identified as particularly at risk from climate change, due to likely increases in crop failure, new patterns of pests and diseases, lack of appropriate seed and plant material, and loss of livestock (Taylor et al., 2016; Iese et al., 2020). These types of impacts are already reducing the growth in productivity of agriculture across most of the globe (Ortiz-Bobea et al., 2021). In the South Pacific region, recent shortfalls in agricultural production resulting from climatic variations and changes, in addition to changing export markets, commodity prices, population growth, and urbanization, have meant a greater reliance on imported foods, thus contributing further to regional food insecurity concerns for the future (Taylor et al., 2016).

In Papua New Guinea (PNG), the largest Pacific Island nation, around 80% of the food consumed is grown domestically (Iese et al., 2020). Historical analyses have shown that the variability of food production is strongly correlated with climate variability. For instance, a strong El Niño event typically reduces rainfall significantly below the mean in otherwise wet regions for extended periods, prolonging dry seasons, generating drought conditions, and reducing cloud cover (Smith et al., 2013). A decrease in rainfall can contribute to water stress and reduced crop productivity. Furthermore, the reduction in cloud cover and drier atmospheric conditions that promote radiative cooling in the highlands of PNG can also increase the probability of frost damage to crops (Smith et al., 2013). While there is still uncertainty around the extent to which elevated greenhouse gas concentrations will affect El Niño Southern Oscillation (ENSO), increasing rainfall variability associated with ENSO-like conditions in the Pacific is highly likely and will further stress agriculture production in PNG (Cai et al., 2014; Lee et al., 2021). Current and historical impacts are a portent of what can be expected to occur under projected climate changes.

The observed and projected climatic changes expose farmers increasingly to conditions outside of those they regularly experience, requiring new knowledge and adapted practices to respond. Farmers have begun to respond to stresses by altering planting times, shifting to better-adapted varieties of crops and livestock, improving soil organic matter, adopting agroforestry and low-carbon farming, and relocating farms (Iese et al., 2020). However, farmers will need to make the sufficient and efficient adjustments and potentially transformative changes in the face of worsening climate impacts (Rickards and Howden, 2012), which will require drawing on novel tools tailored to their needs.

This study aims to understand the information needs of farmers in order to assist the design of knowledge, tools, and practices to enable effective adaptation to climate variability and change. While there is a plethora of tools and knowledge that could be useful to farmers trying to adapt to climate variability and change, barriers related to accessibility, context, and use continue to persist (Hewitt et al., 2020). It is therefore critical to identify what factors influence adoption and adaptation of farm practices, and how to design fit-for-purpose information systems (Shepherd, 2019).

Informing Farm Adaptation

Access to extension and weather and climate information services has been shown to increase the abilities of farmers to adopt better management practices and adapt to climate variability (e.g., Belay et al., 2017; Juan, 2018). Such information services translate weather and climate information into advisories that can aid decision-making, such as supporting farm management choices (Tall et al., 2018). In the farm-level management context, weather and short-term climate information at timescales of days, weeks, months, and seasons are of greatest interest and use (Nkiaka et al., 2019). While weather and climate information can be produced through a variety of sources and methods (Singh et al., 2018), packaging it as an information service requires tailoring content and delivery so that it is salient for end users (Tall et al., 2018; Nkiaka et al., 2019).

Previous research has shown that access to weather and climate information can improve farmers' awareness of climate change, including what climate change is, the impacts it can have, and constraints to adapting (Roco et al., 2015; Habtemariam et al., 2016; Ng'ombe et al., 2020). Studies have also shown that smallholder farmers who have access to weather and climate information—particularly seasonal and sub-seasonal scale forecasts—are more likely to implement climate adaptation strategies, including late or early plantings, use of early maturing crops, agroforestry practices, and soil and water conservation measures (Belay et al., 2017; Dewi and Whitbread, 2017). Such climate and weather information is especially valuable where farming is vulnerable to climate variability, such as in smallholder rainfed systems (Meza et al., 2008), like those in PNG.

The form and content of weather and climate information can vary based on available resources, as well as the intended purpose or use of this information. Seasonal climate forecasts, one family of products that can guide choices farmers make, can reduce uncertainty for farmers when implemented systematically, by enabling them to differentially weight the possible outcomes in a season (Meza et al., 2008). Studies have shown that seasonal climate forecasts should be produced and have relevance at different levels—from national or regional, down to the local—in order to be context relevant and action orientated (Bouroncle et al., 2019). For example, in Colombia and Guatemala, Bouroncle et al. (2019) identified monthly and seasonal climate and agro-climatic bulletins and daily (agrometeorological) forecasts as available to farmers. Broadly, this information was used to advise on agricultural activity planning, provide early warning of extreme climate events or food security alerts, and for organizational planning. Conversely, a study in the Pacific Island nations of Vanuatu, Niue, Solomon Islands, and Tonga examining the types of information local communities used, found that most people preferred to use traditional knowledge-based forecasts, except during extreme events like cyclones, when contemporary forecasting systems were used (Chambers et al., 2019). In PNG, agricultural extension services encompass communication and learning activities for agrarian communities ranging from agronomy and cultivation, to business and marketing, to engineering and technology (Sitapai, 2012). However, current agricultural extension services do not explicitly integrate weather and climate forecasting.

What Affects Information Access and Use?

Often, the one-size-fits-all model for available information products doesn't account for regional cultural discrepancies, local physical conditions, or the needs of different populations. There is evidence from studies in Africa that broadly similar needs may exist across the continent, but information must be tailored for different socially-constructed user groups (Nkiaka et al., 2019). Gender has been highlighted as a critical factor in dictating the necessary content, form, and dissemination of weather and climate information services (Farnworth and Colverson, 2015; Chanana et al., 2018). In many cases these divergent information needs are attributed to established gender roles and unequal participation in decision-making (Jost et al., 2016; Mehar et al., 2016). As an example, in a study in Bangladesh, men were responsible for on-the-ground agricultural activities, marketing, and managing farm proceeds, while women undertook post-harvest work and livestock production (Jost et al., 2016). These roles meant men sought out climate information relevant to land preparation, cultivation, and crop varieties, while women sought information relevant to new income-generating activities, credit schemes, and coping mechanisms for times of food insecurity. Similarly, information needs varied in Ghana, where men reported accessing and using weather information to plan cropping areas and varieties, as well as household protections from storms (Jost et al., 2016). Conversely, women accessed information suited for planning their household chores, like firewood and water collection, milling, cooking, and washing. Research in Africa and Asia has argued that differences in access to assets (e.g., land, financial, natural, social) between men and women underpin adaptation strategies and consequently the types of weather and climate information required (Aryal et al., 2020, 2021; Islam et al., 2021). Following an intersectional approach, other socio-demographic factors, such as education, age, social status, and income have also been shown as influencing adaptation strategies in smallholder farming (Belay et al., 2017; Friedman et al., 2018; Tall et al., 2018; Carr et al., 2020; Lawson et al., 2020).

While a range of forecast tools and knowledge exist, they are often not contextualized or translated in ways that encourage or facilitate decision-making and adaptation (Lemos et al., 2012; Hansen et al., 2019). Review articles have identified and elaborated on a number of broad constraints and facilitating factors that influence access and use of climate information products, particularly climate forecasts. The relevance and credibility of the information and the legitimacy of processes are critical predisposing factors to adoption (Cash and Buizer, 2005). In sub-Saharan Africa, constraints relate to the information content, access to forecasts, and availability of resources to act on information (Hansen et al., 2011). Another global review outlined the issues of fit, interaction, and interplay as three areas of barriers and opportunities for using climate information services (Lemos et al., 2012). For this study, we examine aspects of fit, including the salience, timeliness, and utility of the information. To ensure weather and climate information products are accessible and of use to farmers, it is critical to understand and integrate considerations for what types of information are actually desired and applied, what they are used for, and at what points in the year, in addition to how information services can be best delivered.

With limited resources, and imminent climate threats, it is important to design weather and climate information services in the most efficient manner possible, while also ensuring that the needs of key potential users are addressed. Identifying clusters of information requirements within and between communities can facilitate the development of information products in a way that both captures the range of information and limits the amount of redundancy between products. This study aims to improve our understanding of how weather and climate information services can be developed to better fit farmers' needs in order to modify and adapt their goals, manage risks, and strategically implement management practices in the face of climate change. Specifically, we asked:

1. What are the information types and timings that smallholder farmers require to address the risks associated with weather extremes and variability in a changing climate? And for whom?
2. How is this weather and climate information applied to farm management decisions? And by whom?
3. How could these information needs translate into specific weather and climate information products?

Much of the work on this topic in relation to smallholder farmers has taken place in Africa (Hansen et al., 2011; Nkiaka et al., 2019; Born, 2021), Asia (Sivakumar et al., 2014; Tall et al., 2014; An-Vo et al., 2021; Hossain et al., 2021), and Latin America (e.g., Miralles-Wilhelm and Muñoz Castillo, 2014; Loboguerrero et al., 2018), while little examination of differential weather and climate information needs has occurred in Pacific Island nations. As such, this study helps to fill a critical geographical gap in research on the topic.

MATERIALS AND METHODS

Data Collection and Preparation

In this study, we carried out a household survey in communities across three provinces in PNG: Eastern Highlands; Morobe; and East New Britain (**Figure 1**). Eastern Highlands is one of the coldest regions in PNG, with a temperature range of 15–28°C (mean minimum to mean maximum), and a distinct dry

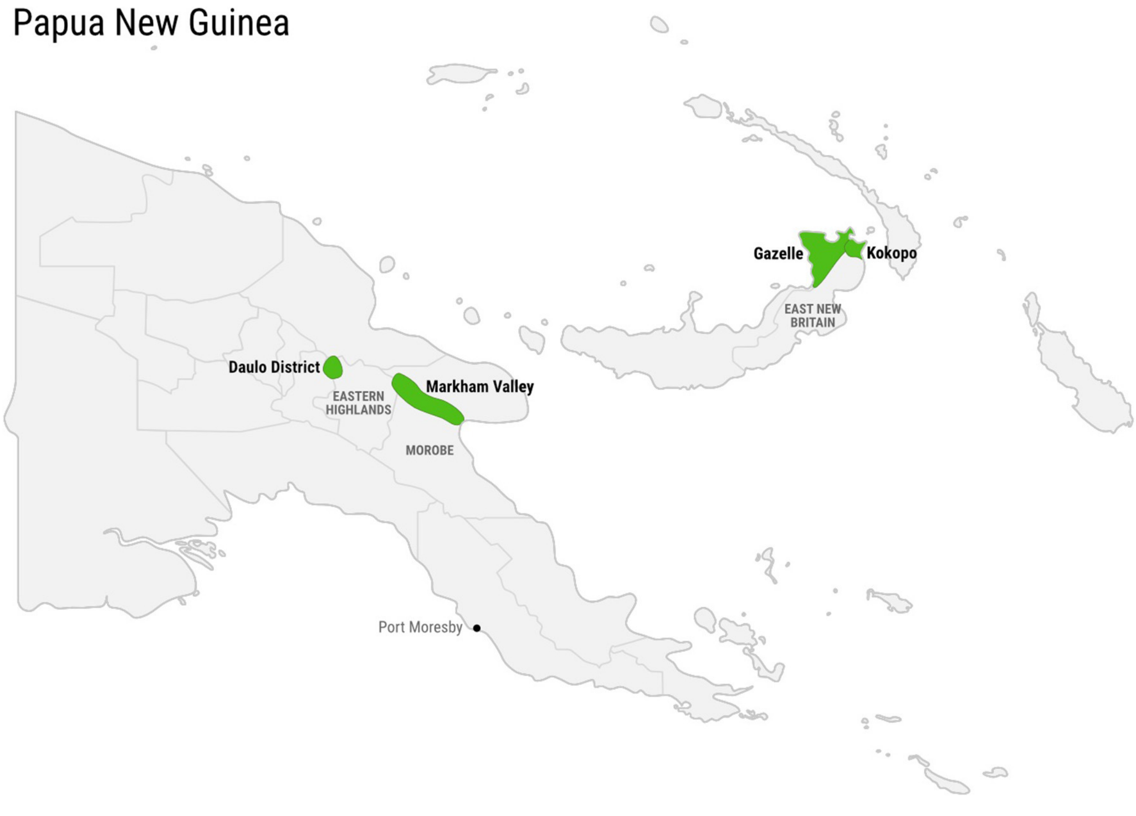

FIGURE 1 | Map of study provinces in Papua New Guinea.

season from June through September (McAlpine et al., 1983; WorldData.info). Morobe province has a warm, relatively stable temperature annually (ranging between 25 and 35°C), with a season of greater rainfall from December through March. However, the Markham Valley in Morobe, where the survey was administered, is the driest area in the province. East New Britain also has a tropical climate, with average temperatures ranging from a minimum 24°C to a maximum of 29°C, and comparatively wetter months between December and April. The country is largely agrarian, with at least 80% of the population reliant on the agricultural sector (Bourke and Harwood, 2009). Food for domestic consumption is primarily produced within the country in low-intensity, rainfed smallholder systems. Although diets vary considerably across PNG, staple foods such as root crops (e.g., sweet potato), sago, and banana, as well as coconut, nuts, and green vegetables are broadly consumed. Many farmers also earn income from domestic and export cash crops. Main export crops are coffee, cacao, oil palm, copra, vanilla, tea, and rubber, while fresh produce is sold at local and urban markets.

Overall, 1,281 respondents were engaged through data collection activities, conducted across two iterations of fieldwork, in October 2018 (Morobe and Eastern Highlands) and October 2019 (East New Britain). Study areas were identified in consultation with the National Agriculture Research Institute (NARI) in PNG to ensure relevance and feasibility, and then villages in each study area were randomly identified.

Survey teams, made up of local Papua New Guinean researchers from NARI and Anglo Pacific Research (APR), followed a stratified random sampling approach to identify respondents, while also filling sampling quotas to ensure a representative spread of the population by gender and age (18–25, 26–40, 41+) in target areas. The survey targeted participants who identified as farmers, were over 18 years old, engaged in crop-based agriculture, and who resided in the study areas. In all surveys conducted, female interviewers interviewed female respondents, and male interviewers interviewed males. All data were collected using the Akvo tablet-based data collection platform. The Human Research Ethics Committee at the Australian National University approved this study (2018/831) before commencing data collection, and all participants gave their informed consent.

The survey was developed to draw out key design considerations for seasonal climate forecasts in terms of timing, content, and use of information, as well as the social networks of information exchange (reported on in a different study). Because participants could provide multiple responses to some of the survey questions, the data was reformatted as binary response variables.

TABLE 1 | Variables used for the study analysis.

Clustering Variables	Description
Receipt of information from others	Binary variable: Yes; No
Important months for weather information and forecasts	Categorical variable: January; February; March; April; May; June; July; August; September; October; November; December
Important types of information	Categorical variable: rain-seasonal; rain-three monthly; rain-monthly; rain-weekly; rain-daily; temperature-weekly; temperature-daily; drought-season; frost-daily; tidal-daily; wind-daily; flooding; other
Information uses	Categorical variable: land preparation; crop type; planting times; transplanting seeds/seedlings; fertilizer application; application of insecticide/herbicide; harvest timing; taking produce to market; collection of produce from the farmer.
Predictor variables	**Description**
Weather impacts on farming activities	Categorical variable: land preparation; crop type; planting times; transplanting seeds/seedlings; fertilizer application; application of insecticide/herbicide; harvest timing; taking produce to market; collection of produce from the farmer.
Biggest challenges in accessing and using weather information	Categorical variable: not frequent; not locally relevant; not understable; not good quality; not trustworthy; no access
Socio-Demographics	Categorical variable: province
	Categorical variable: age (range)
	Binary variable: male; not male
	Categorical variable: education level (block)
	Categorical variable: occupation
	Categorical variable: garden purpose

Data Analysis

In the first instance, we used descriptive measures and statistics to understand how information needs were distributed across groups. Chi-Square analyses (with contingency tables) were carried out using the "gmodels" package (Warnes et al., 2005), to identify whether differences in the clustering variables existed based on the gender of farmers or their geographic locations.

Cluster analysis provides a useful method to examine the intersection and groups of multiple variables simultaneously. The variables related to timing, types, and uses of information were used to examine how climate and weather information could be bundled to form discrete information products (**Table 1**). To delineate particular profiles of information, we performed k-medoids cluster analysis using the "cluster" package (Maechler et al., 2021). Gower distance was used in the computation of pairwise dissimilarities. The number of clusters ($k = 5$) was determined using the silhouette method, an internal validation approach that compares silhouette measures indicating similarity of a data point to its own cluster compared to other clusters, for different numbers of clusters.

Once clusters were defined, the dominant information needs for each were summarized and described. Individual respondents were assigned a cluster number based on the fit of their responses. To better understand what characteristics could influence cluster membership, we used chi-square analyses between cluster number and socio-demographic variables. We also included perceived challenges to accessing and using information in the analysis in order to highlight potential barriers to rolling out the different cluster information products. All visualizations were created using ggplot2 (Wickham, 2016).

RESULTS

Information Types and Timing

The majority of farmers have similar needs in terms of information type and timing. However, patterns of divergence begin to emerge when broken down by gender and province (see **Supplementary Table 1**).

Seasonal rainfall is the most broadly desired information, followed closely by weekly and daily rainfall forecasts, drought warnings, and daily and weekly temperature forecasts. Men and women have distinct information needs ($\chi^2 = 309.46$, df $= 11$, $p < 0.001$). Men primarily want seasonal rainfall and drought information, while women relatively consistently cite seasonal and daily rainfall and daily temperature forecasts. The biggest discrepancies by province ($\chi^2 = 609.58$, df $= 22$, $p < 0.001$) are in East New Britain, where men cite daily wind information as important. Women favor rainfall and temperature as weekly forecasts in East New Britain, but on a daily timescale in Morobe. Rainfall is generally more important than temperature for women in the Eastern Highlands.

June is the most frequently-cited month for receiving information, followed by September and January. However, gender ($\chi^2 = 69.671$, df $= 11$, $p < 0.001$) and provincial ($\chi^2 = 244.56$, df $= 22$, $p < 0.001$) differences in key months are pronounced. September is more important for women, while July and January are for men. In Morobe, June is clearly the most important month to receive information, but September is relatively more important in Eastern Highlands Province and East New Britain for women, and January is for men in East New Britain and women in Morobe.

Information Uses

While some uses of climate and weather information dominated (**Supplementary Table 1**), these also varied by gender ($\chi^2 = 60.78$, df $= 11$, $p < 0.001$) and province ($\chi^2 = 155.07$, df $= 16$, $p < 0.001$). Women more often than men cited the use of weather and climate information as being important to inform planting and harvest times, while men cited using information to inform crop choice and market-related activities more than women. Both noted the importance of rainfall forecasts to inform land preparation, but this varied by gender and province; men more often cited this use in East New Britain and women in the Eastern Highlands and Morobe. The other main divergence of this type was women using information to transplant seedlings in East New Britain, while men were more likely in the Eastern Highlands. Weather and climate information guided fertilizer and insecticide application essentially only in the Eastern Highlands, and primarily for women.

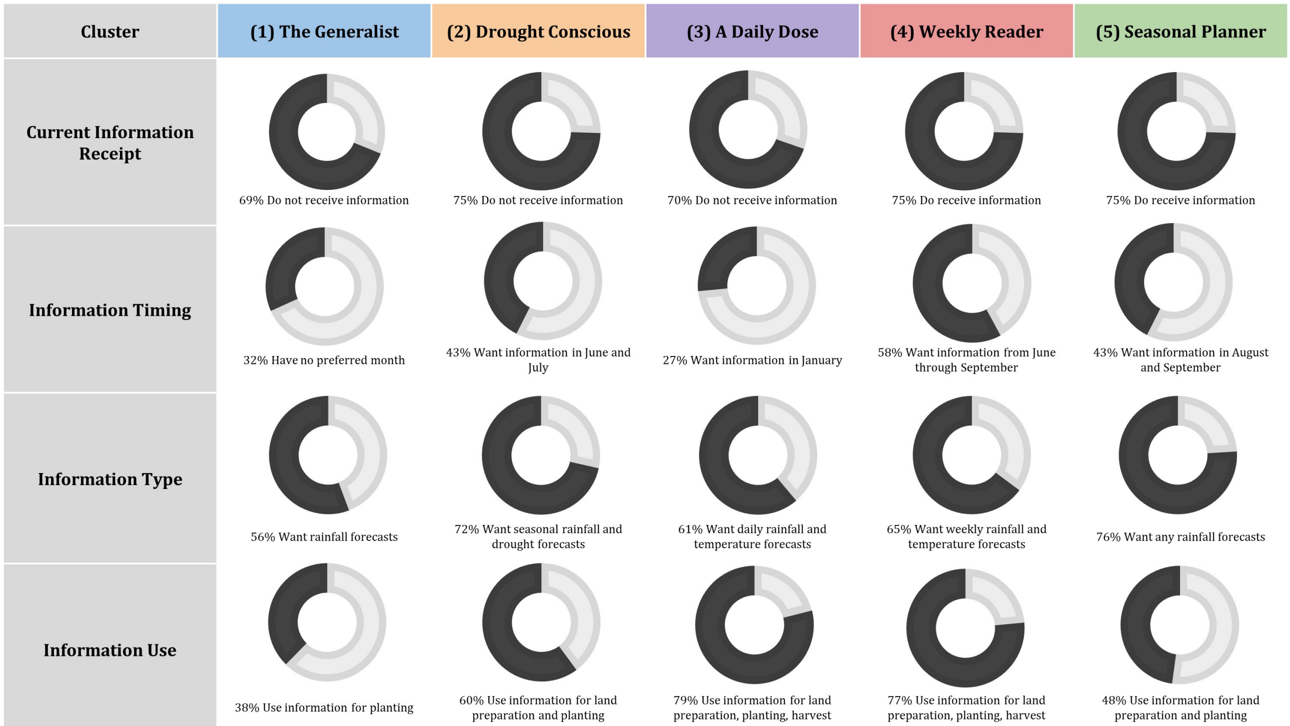

FIGURE 2 | Typology of climate information needs based on the cluster summaries.

Clusters—Information Needs Profiles

Five clusters of information needs were identified through the cluster analysis. The distribution and composition of the clusters reflect the skewed nature of the data itself. Membership of clusters ranged from 155 individuals to nearly 500 (**Supplementary Table 2**), highlighting groups that may have more specialized information needs to meet. The profiles of the identified clusters are found in **Figure 2**.

Most respondents fall into the first (n = 470) or second (n = 294) clusters. The majority of members in those clusters do not currently receive information (69% and 75%, respectively). Nearly one-third of members in cluster 1—**"The Generalists"**—identify all months as being equally important for receiving information. Daily temperature, and daily, weekly, and seasonal rainfall forecasts are the most important types of information. It is also the only cluster where frost forecasts are desired. Information is used primarily for determining when to plant, and then preparing the land and optimal time for transplanting seedlings or cuttings. Cluster 2—**"Drought Conscious"**—focuses mostly on the dry months of June and July, and seasonal forecasts of rainfall and drought. This information is used primarily to determine land preparation and planting, but to some extent the choice of crops and when to harvest.

Most members in Cluster 3 (n = 155)—**"A Daily Dose"**—do not currently receive climate or weather information (70%). Members of this cluster primarily desire daily temperature and rainfall forecasts, with some wind and flooding information. January (wet season) is seen as the most important time to receive information. Members of this cluster use information to plant, prepare land, and harvest crops. Members of the fourth cluster—**"Weekly Readers"**—already receive information (75%), and use it for land preparation, planting, and harvests. Weekly temperature and rainfall forecasts form the basis of this cluster, primarily for the dry months (June, July, and September). Finally, the fifth cluster—**"Seasonal Planner"**—is characterized by a majority of members currently receiving information (75%) for a broad range of uses. While still low, application of fertilizer and pesticides is most prominent in this cluster. The end of the dry season (September and August) is considered most important for receiving information, particularly seasonal and daily rainfall forecasts.

Targeting Information Products

Gender

There are significant differences in cluster membership based on gender (χ^2 = 68.63, df = 4, p < 0.001). While Cluster 1 is nearly gender-equitable, Cluster 2 is composed of about two-thirds (66.7%) male, and Clusters 3–5 have predominantly female membership (60–65%). See **Figure 3** for breakdown of clusters by gender and province.

Province

Cluster membership is also tied to province (χ^2 = 289.72, df = 8, p < 0.001). Around half of Cluster 1 membership is from East New Britain. Clusters 2 (46.6%) and 3 (63.9%) have greater membership from residents of Morobe province. Eastern

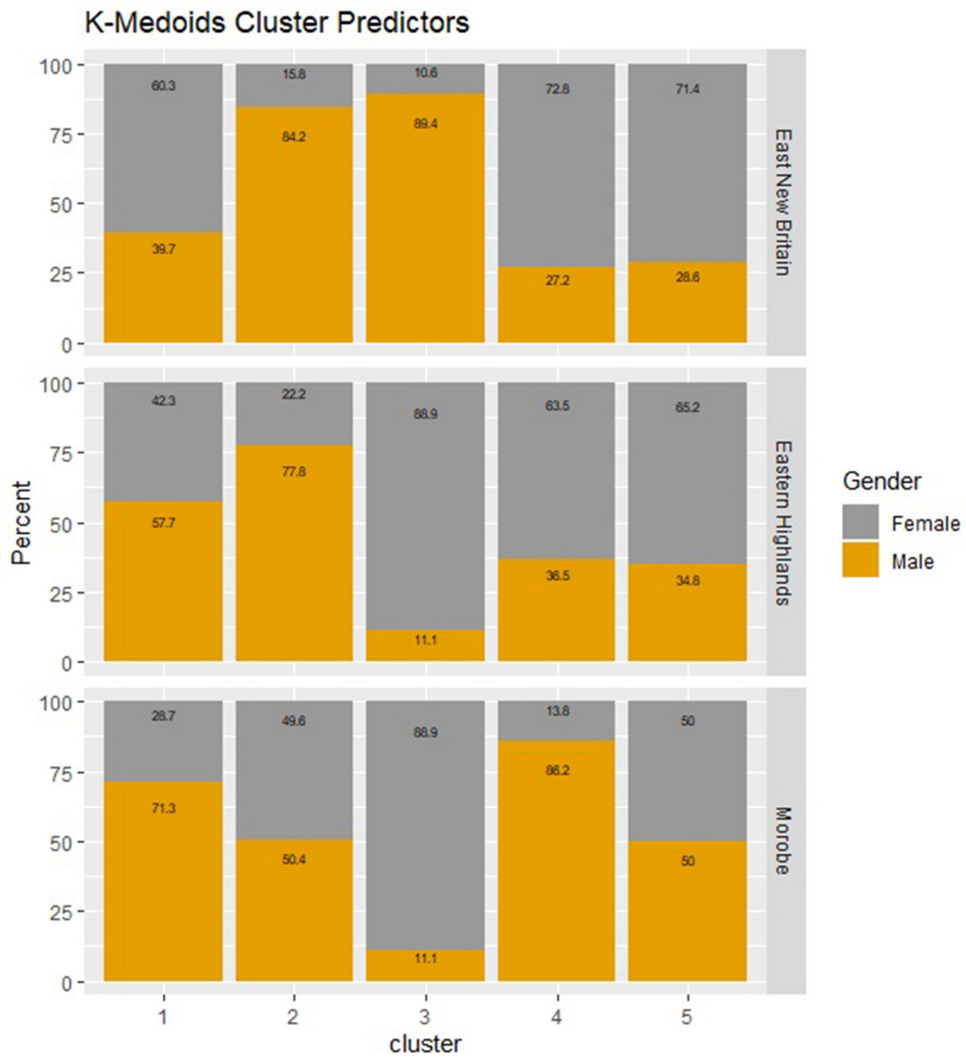

FIGURE 3 | Gender and provincial composition of cluster membership. Values are percentages within cluster.

Highlands (43.6%) and East New Britain (41.5%) share their prominence in Cluster 4. Eastern Highlands residents are most prevalent in Cluster 5 (68.9%).

Education

There are no significant variations in cluster membership based on education ($\chi^2 = 17.37$, df $= 12$, $p = 0.13$). Most respondents have completed primary or secondary education, thus those education levels dominate by sheer numbers, contributing to the lack of significant variation between clusters (**Supplemental Figure 2**). Percentage-wise, compared to other clusters, secondary school is most prominent in Cluster 1 (43.0%) and 4 (46.2%). Similarly, as a product of percentages within clusters, primary schooling is most prominent in Cluster 2 (35.0%) and Cluster 5 (37.1%). The highest rates of no formal schooling are in Clusters 3 (22.6%) and 5 (17.4%). And while only a small proportion of respondents have a tertiary or vocational education, they are comparatively more likely to be found in Cluster 1 (11.7%), with the most well-educated women in Cluster 2.

Occupation and Scale of Operation

While the majority of respondents state that farming is their primary occupation (60%), there are still significant differences between clusters ($\chi^2 = 206.81$, df $= 24$, $p < 0.001$). For instance, those in "other" occupations—self-employed, unemployed, and retired—are most apparent in Cluster 1 (16.4%). Those working at home or in a domestic capacity are prevalent in Cluster 3 (18.7%), and respondents employed as market operators, either at markets or selling to third parties, are most often found in Cluster 5 (21.6%). Students, government employees, and other wage earners are in the minority, and did not demonstrate any particular patterns. In terms of scale of operation, there were minor differences between cluster ($\chi^2 = 29.88$, df =

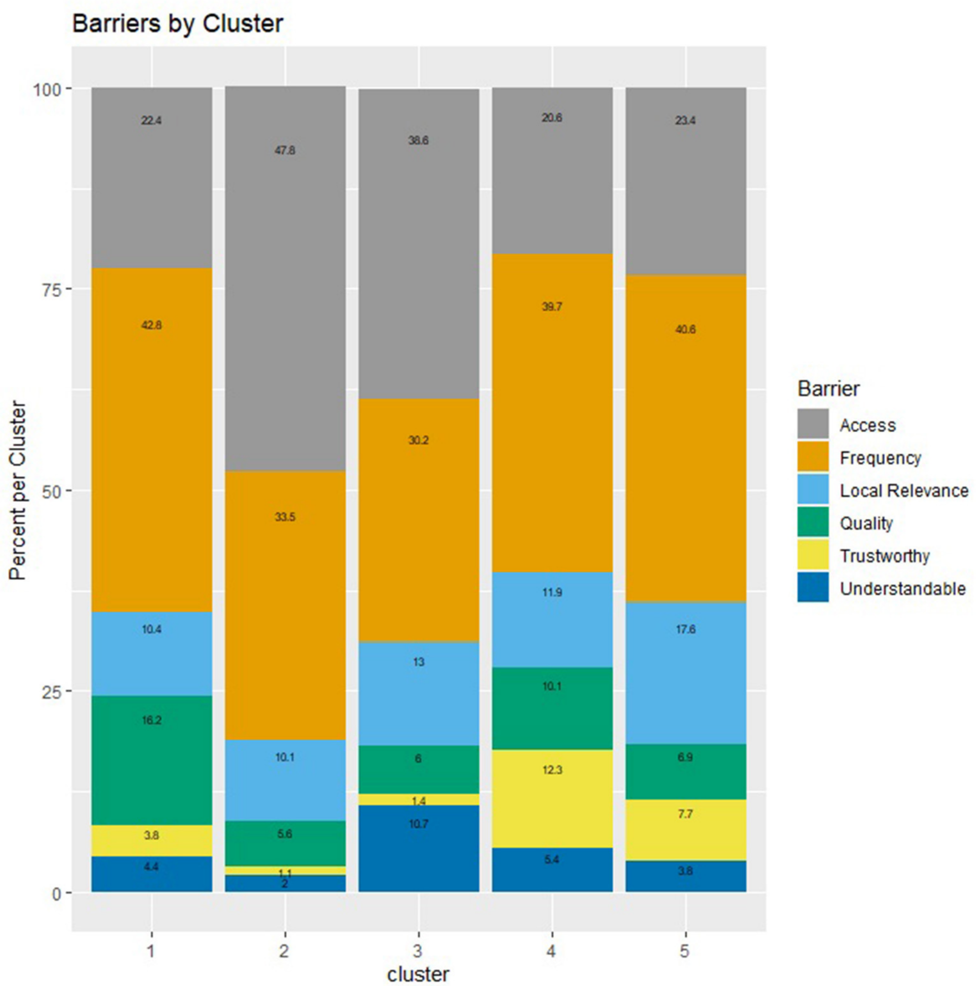

FIGURE 4 | Distribution of perceived barriers to accessing and using climate information by cluster. Values are percentages of the barriers within the cluster.

12, $p = 0.003$), although producing crops for both sale and subsistence dominated across clusters. The only major divergence was in Cluster 1, which had more subsistence-only farmers than expected.

Barriers

Perceived barriers also correspond to certain clusters ($\chi^2 = 213.37$, df $= 32$, $p < 0.001$) (**Figure 4**). The frequency of information is seen as the dominant barrier for Clusters 1 (42.8%), 4 (39.7%), and 5 (40.6%). Lack of access to information is clearly the most critical barrier for Cluster 2 (47.8%), and also important for Cluster 3 (38.6%). Information not being relevant to the local context is perceived as a barrier most in Cluster 5 (17.6%). Poor quality of information is mostly seen as a barrier by members of Cluster 1 (16.2%). Information considered not trustworthy is seen as a major barrier primarily by those in Cluster 4 (12.3%). And finally, difficulty understanding information is perceived as a barrier most by members in Cluster 3 (10.7%).

DISCUSSION

Through this study, we examined how climate and weather information needs differed amongst farmers, in order to guide improved climate information services that are able to enhance adaptation to climate change. We employed a clustering approach to illustrate relationships emerging between multiple climate information variables, demonstrating how desired information content is not consistent across regions or demographic groups. While it is useful to identify broad information needs, these clusters helped pinpoint groups who may otherwise find their interests under represented or marginalized.

Failing to consider how the needs and desires related to climate information services vary runs the risk of overlooking or even undermining the needs of some groups of farmers, and disempowering others to undertake adaptation activities. The distinct profiles of information needs depicted in this study map to social and geographic factors, such as gender, province, and occupation, and provide insights for developing products and advisories aimed at supporting adaptation for specific subsets of the farming population. While clustering algorithms seek to minimize within-cluster differences and maximize differences between clusters, the results of our analysis also show areas of similarities between clusters. This suggests the possibility for core messages and efficiencies to be gained when developing and scaling information services. Finally, it is critical to successfully connect clusters of information content to end users. An understanding of perceived barriers and how information flows in farming communities can facilitate successful integration of information services. Balancing efficient development of climate information services and the specificity of farmers' needs is essential both to rapidly build the capacity, knowledge, and systems to strategically adapt to climate change, and to facilitate more equitable access to and use of critical knowledge for smallholders.

Tailoring for Different Perceived Needs

Appropriately tailoring climate information services may have implications for building farmers' capacity to adapt to climate change, both in terms of ensuring farmers have the information they want, and whether that information supports or informs the sorts of decisions they may need to undertake to address climate stresses. There is evidence from other studies on weather and climate information services, largely in Sub-Saharan Africa, that the use of timely and well-tailored services can in fact prompt such necessary changes in farming practices and improve yields (Hansen et al., 2011, 2019; Nkiaka et al., 2019). However, considering factors such as salience—or the relevance and associated tailoring of information—and equity—inclusion of women, poor, and other socially marginalized groups—are critical for the success of climate information services (Hansen et al., 2011; Tall et al., 2014). Previous studies have demonstrated how the uptake and use of climate information depends on its local relevance (to biophysical, crop, and farmer characteristics) and how well it connects to livelihood or economic impacts for end users (Singh et al., 2018). Our study illustrates how factors, particularly gender and province, in combination can result in distinct information needs that would need to be accounted for in such tailoring.

The information content associated with clusters has implications for how effective information services might be at supporting the capacity to adapt to climate variability, extremes, and shifts. Clusters primarily diverged based on when information was desired and the type of information. In particular, preferences seemed to emerge related to seasonality (focus on wet season or dry season), and forecast length (ranging from a day to the whole season). While both shorter and longer term outlooks have utility when making decisions, the latter are critical for moving beyond coping mechanisms and instituting strategic foresight into farm management (Rickards and Howden, 2012). Clusters 3 and 4 in particular have short-term outlooks, which are crucial for operational management, but could potentially overlook long-term planning or adaptation needs. Whereas, Clusters 2 and 5 are more in-line with what we'd assume to be beneficial to farmers making plans in the face of climate change, such as early warnings for extreme events and seasonal forecasts. Seasonal forecasts are often used to make more tactical decisions around what seed varieties to choose, purchase of inputs, and spatial planning; whereas shorter-term daily and weekly forecasts are used to make calculated micro-adjustments to planting, applications, harvesting, and other operations (Nkiaka et al., 2019). Furthermore, repeated use of seasonal forecasts may help farmers to distinguish shifts over time and adjust to longer-term changes (Singh et al., 2018). While climate information that extends beyond the seasonal time-frame is considered valuable to achieving more transformative changes in response to novel climatic conditions, it is however often poorly suited to the types of decisions farmers need or are able to make at local levels (Singh et al., 2018).

The results of the cluster analysis show that prominent information needs vary by region and gender. In PNG, research has shown that while men are considered to be the heads of households and as such dominate decision-making particularly for cash crops (Eves and Titus, 2020), women are still involved in most aspects of agricultural production and tend to have greatest input into planting and harvesting of food crops and general maintenance tasks (Bourke and Harwood, 2009; Curry et al., 2019). It is therefore understandable that information needs might diverge based in some part on gender. Clusters 3, and 4 have majority female membership and tend to focus on shorter temporal windows (i.e., daily, weekly), which may support their primary farming roles but not be as conducive to adapting to climate change in the long-term. While both the majority female Cluster 5 and the majority male Cluster 2 prioritize information and timing that helps address periods of seasonal water scarcity, men claim they need information early in the dry season (June/July) and women toward the end (September). This highlights potentially distinct uses for the information, or constraints dictating optimal timing. Previous research corroborates these patterns, showing how the information needs, access, and uses for men and women may diverge in agricultural systems (Archer, 2003; Tall et al., 2014; Farnworth and Colverson, 2015; Carr and Owusu-Daaku, 2016; Diouf et al., 2019; Partey et al., 2020). For instance, in a case study in Senegal, researchers found that women farmers preferred to know about the cessation of seasonal rainfall, rather than onset (Tall et al., 2014). A study in Ethiopia showed that although women household heads were less likely to access quality extension services, receiving advice was positively related to adoption of improved varieties and inputs (Ragasa et al., 2013). As such, ensuring the timing and type of information matches users' needs is crucial to producing useful information products.

There are also geographic influences on the information needs of farmers, which could be both biophysically driven or underpinned by cultural differences or existing *in situ* information networks (Vogel and O'Brien, 2006; World Meteorological Organization, 2015). However, for Papua New Guinea, the nature of these connections is still speculative, as research on the topic is limited, and more research is needed to develop an understanding about cultural and social underpinnings of regional information needs. The survey region in Morobe is exceptionally dry, which aligns with the focus of

Cluster 2 on drought information early in the dry season (June). Eastern Highlands had a strong representation in Cluster 5, which favors rainfall information at the end of the dry season (September). This is a prominent transition month in the region, and could therefore be an important period of preparation for the wetter season. East New Britain was best represented in the General Cluster 1, which notably showed little temporal preference, probably reflecting the more stable, tropical climate there and hence smaller fluctuations in information needs across the year. Clusters 3 and 4 were less straight-forward, which may reflect farmers' perceptions around uncertainty and the interannual variability related to such forces as ENSO. For instance, Cluster 3 (Morobe dominant) centers on daily rainfall and temperature forecasts during the wet season (January), which is the peak of the wet season. The cluster comprises more women, those working in domestic occupations, and with the highest levels of no education, who all may perceive their information needs differently from the other clusters.

Practicalities and Efficiencies

While there are apparent distinctions in the information needs within the study area, the commonalities between clusters suggest there are also opportunities to gain efficiencies even when aiming to develop tailored forecasts. The process of translating broad climate information into context-specific products is resource intensive (Kalafatis et al., 2015), and there are trade-offs between individual user specificity and the practicalities associated with the timeliness and feasibility of information services (Dunn et al., 2015; Carr et al., 2020). As such, it is critical to achieve a balance between customization and universality in climate information services. While "scaling up and out" is a common refrain in the literature on climate and agricultural information services, there are considerable knowledge gaps, particularly in relation to the trade-offs between scale and local efficacy (Carr et al., 2020).

Results from this study provide initial insight into balancing efficiency and tailoring, which could be beneficial to achieving scalable climate information services. About one-third of respondents were members of Cluster 1—"The Generalist"—which has broad information needs in terms of timing, type, and uses. This demonstrates there is a perceived need for a more generalized information service, which could form the base in developing targeted advisories. All five clusters also overlapped considerably in terms of information uses, especially land preparation and planting time, suggesting a common suite of advice "types." However, the actual recommendations for farm management would vary depending on the local forecast conditions.

These findings support an approach to farm advisory development that incorporates a foundation of general information to satisfy the needs of most farmers, with additional tailored information for particular groups depending on the context. Our approach to developing a tailored "Seasonal Farm Advisory" in PNG first involves establishing a robust and relatively comprehensive table of farm management recommendations for a range of crops—particularly staples ones like banana, cassava, sweet potato, and taro—based on the available seasonal forecasts and creating a composite "base" document (see **Supplemental Figure 3** for crops in the survey). Targeted advisories can then be compiled from this composite document to reflect the needs of specific farmers, as demonstrated through the cluster analysis. This aligns with the modular design principles outlined by Koerner et al. (2021), which increase the diversity of options for users by enabling the use, reconfiguration, or repurposing of different components of the service. The authors argue that this mixing-and-matching can accelerate the process of scaling, multiplying the possible uses or contexts in which climate information services are relevant.

While the approach outlined in this paper can help guide the development of climate information services that meet needs of regional groups of farmers, and tracking these needs over time, there are still challenges to effective scaling that go beyond information services content (Tran et al., 2020). This requires institutions to work with farmers on the communication and use of climate services, and for information providers to be responsive and accountable to the evolving needs of farmers.

Implications for Communicating Information

While the clusters depict distinctions in information content, it is also essential to consider how to connect the information services with users. To overcome the barriers to scaling effective and equitable climate information services, studies like this one must be considered in tandem with complementary studies on information flows and communication strategies. These areas have decades of experience testing different models for producing and disseminating seasonal climate forecasts in Sub-Saharan Africa. In a review of these models, Jost (2013) identified radio, demand-driven extension, and mobile technology as key channels available for movement of climate information to farmers. Interpersonal and information networks within communities can also be critically important (Nkiaka et al., 2019). For example, a study in Ghana looked at the influence of mobile phone delivery of climate information, finding that the adoption of some adaptive practices improved (water management, multi-cropping), while others did not significantly change (e.g., erosion control, IPM, and resistant crops), suggesting the role of different communications channels in adoption (Djido et al., 2021). Because there are differences in access to, and use of, climate information communication channels between groups of farmers (e.g., McOmber et al., 2013; Djido et al., 2021), targeting information has relevance for both content and communication. As such, overcoming communications hurdles and other barriers is crucial to actually informing adaptation.

In this study, the discrepancy between respondents who currently receive information and those who don't highlights how communications strategies may need to differ between clusters. The majority of members in Clusters 1, 2, and 3 said they currently receive no climate or weather information, which adds the challenge of establishing appropriate channels to enable access to information to support adaptation. This raises an important question of when is it possible to tap into existing effective communication channels, and when new ones need to be created and cultivated in order to ensure desired information is accessible. There are likely opportunities to build on existing information exchange networks in PNG, particularly informal and community-based ones (Friedman et al., 2022), but in some cases building communication channels from scratch may be necessary. Furthermore, choice of information channel may also dictate the content, and so relying solely on existing networks may be limiting. Research on climate information and support services demonstrated how the choice of channel can influence what type of information is conveyed, particularly to marginal or vulnerable groups (Cherotich et al., 2012). Finally, a study in Ghana highlighted how the choice of communication channel impacts the successful adoption of climate adaptation measures. Membership in a farmer-based organization and access to extension services were both significantly positive influences on adopting adaptation measures (Owusu et al., 2021). This highlights how interwoven the content and communications sides of climate information services are to achieving outcomes.

Tailoring both content and communication can address barriers related to relevance, accessibility, and uneven distributional impacts (Vaughan and Dessai, 2014; Hansen et al., 2019). Barriers to information use, including the quality of information, local relevance, trustworthiness, and understandability, map more directly onto some clusters over others, suggesting possible challenges that need to be addressed for certain types of information, regions, or groups of farmers. For example, local relevance and understandability are relatively major challenges for Cluster 3, which had the greatest number of members without formal education and from a unique region in Morobe. While education levels were not significantly related to membership in a climate information cluster (i.e., desired content), they could have substantial impact on the feasible means of communicating this information, due to differences in literacy and familiarity with scientific concepts and uncertainty. Furthermore, research has highlighted how confidence in one's awareness and understanding of climate change can influence use of such information and adoption of adaptation measures (Ng'ombe et al., 2020; Nguyen and Drakou, 2021). As such, efforts could be focused on translating information into easily understandable and actionable formats. Trust and quality were relatively important for Clusters 4 and 5, which were also dominated by women, who tend to face greater barriers to accessing information. Here, taking an interactive approach to the design and dissemination of climate information, and improving institutional communication, could help overcome trust and related barriers (Lemos et al., 2012; Kumar et al., 2021; Belay and Fekadu, 2021). Accessibility was the overwhelming barrier for Cluster 2, hinting at the existing challenge of obtaining drought warnings in PNG. Overall, accounting for the perceived barriers hindering integration of climate information should be an integral part of the strategy for developing climate information services.

Caveats and Future Research

The survey and clustering results from the study present a useful starting point to develop more refined and user-oriented climate forecasts and advisories, yet there are also a number of considerations when examining the data. For one, the survey is taken at one point in time, but information needs do change throughout the year and over time. While this study provides a snapshot of how information needs may cluster at a given time, only longitudinal data will give us a sense of whether clusters and membership are stable or shift over the course of a year or between years. Further analysis should include data collected during both wet and dry seasons, and ideally over multiple years (including both El Niño and La Niña years).

This analysis demonstrated how different information needs manifest within and between communities. For instance, clear differences in the information needs of men and women emerged in this study. Additional research could provide nuance on what drives these differences, such as specific gendered roles and cultural norms, as well as decision-making responsibilities. Qualitative methods, such as focus groups and interviews can provide a stronger narrative behind why these gendered and other differences exist. They can also complement the cluster analysis in fleshing out how individual information products could be best tailored for specific groups. Additional quantitative information, such as size of farm and amount of crops produced for consumption and sale, could also improve understanding of what drives differentiated information needs.

Integrating this understanding into the development of climate information services for agriculture requires additional considerations in practice. Unlike in Sub-Saharan Africa, research has shown that in the Pacific Islands farmers tend to have limited reliance on contemporary weather forecasting, instead relying on knowledge of traditional forecasting to reduce negative impacts from extreme events (Chambers et al., 2019). There is thus an opportunity in the region for better integration of contemporary scientific forecasting with existing traditional knowledge to improve interpretation of technical information and ultimately achieve adaptation outcomes. While often discussed as an effective approach to both achieve scale and to ensure local relevance, very little work has been done on co-production of climate information services as a means of integrating traditional knowledge and other social or cultural interests (Carr et al., 2020). More research in this area may be key for facilitating the uptake of reliable forecasting in a manner that is contextually appropriate and locally relevant. However, development of guidelines for co-production principles is still emerging (Bremer and Meisch, 2017), and empirical evidence of the scalability of such strategies remains a gap.

Finally, this study focused on the content and timing of weather and climate information services, but not the dissemination. While the barriers to access and use of information included in the analysis provide some clues about what hinders communication, more research is needed to understand how farmers can actually obtain this information. In the particular context of PNG, it would be valuable to elucidate how farmers who currently use weather and climate information access it, and conversely what information is actually available that farmers are unaware of or are unable to access. This baseline research is foundational for setting up weather and climate information services that not only reach farmers but also cater to their needs.

CONCLUSION

Ultimately, the results of this study have shown the value in identifying how weather and climate information needs vary within and among farming communities, while also highlighting the complexity of accounting for multiple intersecting population traits when designing information services. Through this study, we aimed to identify how different types, timing, and uses of weather and climate information intersected, and who most desired these bundles of information to inform their farm management practices under climate variability and change. We found that gender and variables associated with geography played a role in shaping information needs, and could be used to help tailor specific climate information services. With limited time and resources, it is also necessary to find efficiencies in the development of these services. We proposed capitalizing on common uses of information across clusters, and using a modular approach to create specific tailored products. Finally, this study focused on the content of weather and climate information services, and how that may need to vary for different groups of farmers. However, the results of this study must be used in conjunction with developing appropriate communication channels to overcome perceived barriers to accessing and using information. Accommodating different needs in the design and delivery of weather and climate forecast services could substantially enhance their relevance, credibility, and legitimacy amongst smallholder farmers, with resultant improvements in lives and livelihoods across the Pacific.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: "Open Science Framework: https://osf.io/dfnr6/?view_only=1f41000fd5284b5a9d8119aa7ead2c6f".

ETHICS STATEMENT

The study involving human participants was reviewed and approved by the Human Research Ethics Committee at the Australian National University (2018/831). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SC and RF conceptualized the study. RF carried out the analysis. RF, SC, RB, KI, and EM interpreted the results of the analysis. RF, SC, and EM wrote the paper with content and editorial input from RB, KI, and MH. All authors have read and approved the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2022.871987/full#supplementary-material

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