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Seasonal Calendars Enhance Climate Communication in the Pacific

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ABSTRACT: Traditional calendars document seasonal cycles and the communities' relationships to their biophysical environment and are often used by communities, particularly subsistence farmers, to synchronize their livelihood activities with the timing of ecological processes. Because the timing of these ecological processes is not always consistent from year to year, the use of traditional seasonal calendars can help communities to cope with climate variability, particularly when biophysical phenomena become less predictable in relation to the Gregorian calendar, as has been observed in relation to climate change. Although the structure and content of seasonal calendars vary across the Pacific Ocean region, for many indigenous communities, knowledge of seasonal calendars can increase their capacity to cope with climate variability and change. To increase the effectiveness of their products and enhance their relevance to and uptake by the community, several Pacific meteorological services are now using traditional seasonal calendars in their climate communication and education, including in forecasts and warnings. The use of a participatory approach resulted in strong relationships and improved dialogues. Local communities appreciated assistance in enabling their knowledge to become available to future generations, and its inclusion in meteorological service products makes these products more accessible and relevant to community members.

KEYWORDS: Pacific Ocean; Climate prediction; Forecasting; Seasonal forecasting; Climate services; Societal impacts

1. Introduction

For many communities, understanding western scientific terms of climate variability and climate change can be difficult (McNaught et al. 2014). In some locations, including many communities in the Pacific Ocean region, weather, climate variability, extremes, and climate change are words and concepts that may not have a specific equivalent term in local

language and may not be well understood nor easily communicated (Leonard et al. 2013; McMillen et al. 2014; Malsale et al. 2018). However, for indigenous peoples, these concepts may exist as part of interlinked environmental, cultural, and social knowledge rather than as distinct notions (e.g., Hatfield et al. 2018; Nursey-Bray et al. 2019), and this is discussed in more detail below.

For most Pacific Island communities, seasonality is understood in terms of the time of year when terrestrial and marine resources are harvested or when cultural festivities and activities occur. Often, recognition of seasonality and event timing is determined by biological indicators and how they respond to climate, noting that there is no clear demarcation and set time for seasons. In addition, cyclical life cycles and local knowledge of the environment and seasonal changes do not follow the seasons as determined by western cultures, and seasons are interconnected and fluid (S. Lui, unpublished material; Kassam et al. 2018). Local understanding of seasonality, based on traditional knowledge (TK), also known as indigenous knowledge, plays an important role in many communities in building resilience to climate extremes and adapting to climate variations

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and change and is a key determinant of adaptive capacity in the Pacific region (e.g., Lefale 2010; Chand et al. 2014; McMillan et al. 2014; Handmer and Iveson 2017; Warrick et al. 2017). There are growing concerns that TK is being rapidly eroded due, in part, to rapid urbanization, an emphasis on western science, and the apparent changing reliability of traditional indicators due to climate change (e.g., King et al. 2008; Kaniaha et al. 2012; Seuseu et al. 2013; Rivero-Romero et al. 2016), and that this will have negative impacts on the health of environments and people (Balick et al. 2019).

Traditional seasonal calendars (herein referred to as seasonal calendars) have been used to document seasonal cycles and the communities' relationships with their environment (Mondragón 2014; Rubis and Nakashima 2014; Kassam et al. 2018). Consequently, these calendars can be used as effective educational and cultural tools, introducing discussions on environmental issues, including climate variability and change (Lefale 2010; Leonard et al. 2013; Rubis and Nakashima 2014). In addition, seasonal calendars are used by communities to synchronize their livelihood activities, such as agriculture and fisheries, with the timing of ecological processes (McMillan et al. 2014; Kassam et al. 2018; <http://www.bom.gov.au/iwk/>). As the timing of these ecological processes is not always consistent from year to year, the use of seasonal calendars can help communities to cope with climate variability, particularly when the biophysical phenomena become less predictable in relation to the Gregorian calendar (McMillan et al. 2014; Kassam et al. 2018). For many indigenous communities, seasonal calendars are therefore building their capacity to cope with climate variability and change (McMillan et al. 2014; Kassam et al. 2018).

Seasonal calendars have the potential to differ even for closely associated communities, as they are often based on the behavior of local plants and animals (McMillan et al. 2014; Rubis and Nakashima 2014; <http://www.bom.gov.au/iwk/>) and can vary according to local seasonal phenomena even within islands, for example, the typically drier leeward sides as compared with windier and generally wetter windward side (McMillan et al. 2014). Across Oceania, although documented indigenous seasonal calendars exist for some countries and regions, for example, Australia (Mondragón 2014; <http://www.bom.gov.au/iwk/>; <https://www.csiro.au/en/Research/Environment/Land-management/Indigenous/Indigenous-calendars>), there remain significant gaps in where these calendars occur and in the level of detail provided. Differences between calendars can include the number of seasons into which the year is divided and the plants and animals used to mark the change of seasons.

National Meteorological Services (NMSs) in the Pacific wish to better understand and serve their communities and this includes finding alternative, and improved, methods of discussing climate variability and change and enhancing communication of climate products, including forecasts and warnings. This need was identified in Chambers et al. (2019) and in the Pacific Roadmap for Strengthened Climate Services 2017–26 (Pacific Science Solutions 2017), and aligns with the Global Framework for Climate Services goal to improve the resilience of vulnerable regional communities (e.g., small island developing states)

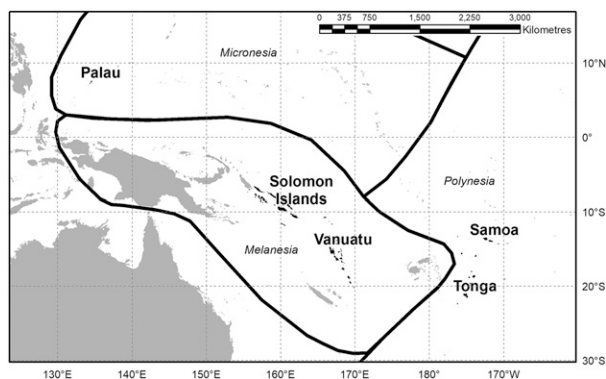


FIG. 1. Map of Pacific Ocean region showing locations of Palau, Samoa, Solomon Islands, Vanuatu, and Tonga.

to climate hazards, by developing stronger partnerships between communities and NMSs to provide targeted and user-friendly climate services that better meet community needs (World Meteorological Organization 2011; Hewitt et al. 2012). This paper discusses how seasonal calendars can assist with climate communication and development of new climate services and how the information used to construct the calendars was collected and used in three Pacific countries: Samoa, Solomon Islands, and Vanuatu (Fig. 1), supplemented with literature reviews for other Pacific nations, in particular, Tonga and Palau.

This paper is written from the perspective of the NMSs and their partners; however, the project was based on, and reflects, regular communication and input from the communities.

2. Methods

Community consultations and literature reviews were the two main approaches used to construct and verify seasonal calendars in the Pacific. The main approach taken differed by country. The Solomon Islands and Vanuatu have multiple islands and language groups (see below), and published knowledge of seasonal calendars across their countries was sparse (see Table S1 in the online supplemental material). Therefore, the use of a common method in each country, with community participation, was preferred. Samoa has a single language group and was aware of previously published seasonal calendars, which they wished to verify (see below). A literature review was undertaken to identify other Pacific Island countries with previously published seasonal calendars.

In each country we used culturally sensitive and inclusive methods to collect and store TK related to seasonal calendar construction, including prior informed consent and attribution of knowledge to cultural groups. Importantly, the following aspects were central to the process of engaging with community members and the storage and use of traditional knowledge: 1) consideration of legal and national contexts, 2) the use of prior informed consent, 3) acknowledging cultural restrictions to access and use of TK, and 4) intellectual property (IP) rights (see Chambers et al. 2020 for further details). Working in partnership with the ministries for culture in each country, helped to ensure all legal requirements were met, including

those designed to protect culture and IP (for more information on specific legal frameworks followed, see [Malsale et al. 2018](#)). Other important country-specific partnerships included the Ministry of Women, Communities, and Social Development (Samoa); Red Cross (Vanuatu); Department of Agriculture (Vanuatu); and Kaltoral Senta (Cultural Centre; Vanuatu). For further details on the role of each of these partners, see [Malsale et al. \(2018\)](#).

The people responsible for working with the communities to document seasonal calendars, the Pacific NMSs and their partners, are indigenous and used their strong ties and existing relationships with these communities to ensure that cultural norms, permissions, and restrictions were appropriately applied. This included discussing project purpose, partnerships, information dissemination, and the ability to restrict access according to any cultural sensitivities with knowledge holders before any community interviews were conducted (see [Malsale et al. 2018](#) for further details). All aspects of the design and governance of this project were indigenously managed, thus providing an example of how indigenous research leadership and sovereignty can be used for environmental decision-making ([Latulippe and Klenk 2020](#)).

The processes used in each country are detailed below.

a. Samoa

Samoa is located close to the international date line in the South Pacific ([Fig. 1](#)). Culturally its indigenous people are Polynesian, where “tomai tuufaasolo” (traditional knowledge) based on observations of plants, animals and the atmosphere guides decisions on fishing, farming, and other daily activities ([Malsale et al. 2018](#)). The government and community members are keen to understand linkages between contemporary science and traditional knowledge based on environmental, ecological, and astronomical indicators, and the development of seasonal calendars is seen as a component of this.

An initial seasonal calendar for Samoa was developed via a literature review, heavily relying on the work of [Lefale \(2010\)](#) and a [Member of the Samoan Society \(1928\)](#). This calendar was then taken to several members of the Samoan community (representing multiple villages), traditional orators, and other environmental experts for discussion and revision, ensuring the accuracy of the final calendar.

b. Solomon Islands

The Solomon Islands is a Melanesian country composed of over 900 islands and multiple language and cultural groups ([Fig. 1](#); [Malsale et al. 2018](#)). As such, seasonal calendars were expected to vary across the country. Three remote regions, representing different cultural groups within the Solomon Islands, were initially involved in the project, as each of these was keen to maintain its strong cultural heritage. These were Nukufero (Russell Islands, Central Province), Olomburi (Kwaio, Malaita), and Gaenu'ualu (Weather Coast, Guadalcanal).

After an initial community and stakeholder engagement workshop in the capital of Honiara, in September 2014, members of the Solomon Islands Meteorology Services traveled to the villages for week-long visits to document traditional climate and weather stories, including seasonal calendar information.

These took place in March 2015 (Gaenu'ualu), June 2015 (Olomburi), and October 2015 (Nukufero, with an additional visit to nearby Somata).

Community discussions were based around the following key questions: 1) what do weather and climate mean in your language? 2) How many “seasons” do you have and when do they occur? 3) What activities do you do in each month of the year? 4) What signs do you look for to predict weather and climate? The information collected during these group discussions was used to build the seasonal calendars and to inform the development of communication products (e.g., forecasts and warnings and climate and weather glossaries; [Chambers et al. 2020](#)). Because women and men, of varying ages, can hold different knowledge of climate in the Pacific region ([Anderson 2009a,b](#); [Lane and McNaught 2009](#)), every effort was made to include the participation of people of varying gender and age categories in the discussions.

c. Vanuatu

Vanuatu is a Melanesian country composed of over 80 islands and over 100 languages. For indigenous subsistence farmers cultural knowledge is reasonably intact and there is a strong dependence on this knowledge for everyday activities ([Malsale et al. 2018](#)). An initial workshop was held in 2012 when community members from around Vanuatu met in Luganville, Espiritu Santo. During the workshop participants felt it was important that large scale and systematic collection of traditional knowledge of seasonal indicators and climate was needed but that procedures and templates were required to ensure consistency ([Kaniaha et al. 2012](#)). Participants were broken into provincial groups (Sanna, Penama, Malampa, Shefa, Tafea, and Torba) to develop draft seasonal calendars.

A subsequent national workshop was held at Pele Island in April 2013 in which volunteer rainfall monitors and experts from the agriculture and forestry department [Vanuatu Meteorology and Geo-Hazards Department ([VMGD 2013a](#))] reexamined the provincial calendars produced at the 2012 workshop. The focus in this workshop was on the timing of planting and harvest of key crop and tree species. Participants were asked to 1) validate the existing information, 2) add missing indicators, and 3) indicate where special forecasts from the meteorological service would be required for specific events, for example, planting or harvesting seasons of major crops. Participants were issued with mobile phones so that they could further verify information with community elders that were not present at the workshop. Although participants were grouped according to provinces, there was some concern that the scale of the province was too large to pick up any island and community differences. This issue was noted but not addressed at this workshop. This workshop also allocated time for participants to discuss ownership and use of traditional weather and climate information.

An additional National workshop was held in Tanna Island, May 2013, to further develop climate services to increase community resilience to weather and climate events and included over 100 government extension officers, from agricultural, forestry, livestock, and environment departments, and local farmers ([VMGD 2013b](#)). Climate services provide climate information tailored to user needs to help communities make

climate smart decisions ([World Meteorological Organization 2011](#)). During this workshop traditional cropping (seasonal) calendars were presented, and discussions held on how to integrate them with meteorological information. Although compiled at the provincial level, these completed calendars can form a template for the collection of location specific information.

d. Additional countries

A literature search for existing Pacific seasonal calendars revealed additional calendars for several Pacific nations. Background for these are provided below and in the online supplemental material.

1) KINGDOM OF TONGA

The Kingdom of Tonga (Tonga) is a Polynesian country composed of 169 islands divided into three main island groups: Tongatapu, Ha'apai, and Vava'u, with 70% of the population living on the main island of Tongatapu. Rural populations are reliant on plantation and subsistence farming.

A literature review was used to search for existing seasonal calendars for Tonga. Two key sources of information were [Collocott \(1922\)](#), which was based on yam phases, and [Tualaufale \(2015\)](#), which was based on astronomy and ancient Tongan political culture ([Fig. 4](#)). The Tonga Meteorological Service (TMS) supports the use of "ilo tukufakaholo" (TK) as documented in [Collocott \(1922\)](#) when communicating scientific or technical weather and climate terms and concepts to their communities, recognizing the wisdom of their elders.

2) PALAU

The Republic of Palau is a Micronesian country composed of over 300 islands in the western Pacific. The country is divided into 16 states, with around two-thirds of the population living on Koror. The economy is reliant on tourism and subsistence farming and fishing.

A literature review was used to search for existing seasonal calendars for Palau. Three key sources of information were [Klee \(1976\)](#), [Takeda and Mad \(1996\)](#), and an online source ([Rak...A year in ancient Palauan; https://merirei.com/rak-a-year-in-ancient-palauan/](#)).

A literature review identified the existence of seasonal calendars for other Pacific countries [e.g., Guam in [Nature Conservancy \(2014\)](#); Fiji in [Nainoca \(2011\)](#); Marshall Islands in [Pacific Islands Climate Science Center \(2017\)](#); Papua New Guinea in [Damon \(1996\)](#); see online supplemental Table S1 for further locations]. Where sufficient details were available, in the discussion section ([section 3](#)) these calendars are compared with those developed here. However, in some cases, full details of the calendars, including the number or timing of the seasons and how they were developed, were not publicly available because of their sensitive cultural nature or for undisclosed reasons, for example, those of Tuvalu ([Secretariat of the Pacific Regional Environment Programme 2016](#)) and the Federated States of Micronesia ([Pam 2015](#)).

e. Verification of calendars

The NMSs in each country produced draft seasonal calendars based on the information collected through the above

community workshops or literature. These draft calendars underwent community consultation to ensure that the information was correctly recorded and attributed, and that consent was obtained prior to publication and use of the calendars by those outside of the communities [see Vanuatu section above ([section 2c](#)) and [Chambers et al. \(2020\)](#) for an example of how this was achieved].

3. Results and discussion

a. Collecting and documenting TK

By their very nature, seasonal calendars are multidisciplinary. This meant that several government departments, non-governmental organizations, and community groups were involved in their development. In addition to community members, the collection and documentation of the information used to build seasonal calendars typically involved NMSs, cultural, forestry, agricultural, and fisheries departments.

The methods used to collect the TK varied by country. The use of national workshops, with representatives from each province/region, were popular in this project, resulting in national or provincial calendars. Countries such as the Solomon Islands also included visits to select communities to collect TK; the process included prior informed consent and agreement that the knowledge would remain the property of the community who provided it. In Samoa, Palau, and Tonga, literature reviews identified existing calendar information and this information was consolidated into graphical seasonal calendars. Basic calendar information was also collected, via a literature review, for other Pacific nations (see the online supplemental material).

Methods used in the literature to collect seasonal calendar information also varied. Some used old journals, such as those from missionaries (e.g., [Kirch 1994](#)), and published and unpublished monthly calendars (e.g., [Roberts et al. 2006](#)). Other calendars were developed through conversations with leaders in local villages (e.g., [Lefale 2003](#)) and field studies and questionnaires (e.g., [Takeda and Mad 1996](#)).

Within Pacific nations, knowledge of and use of environmental information can vary, particularly where this knowledge relates to seasonal or subsistence activities, which are often segregated according to gender ([Balakrishnan 1998](#); [Anderson 2009a,b](#); [Lane and McNaught 2009](#); [Raney et al. 2011](#)). For example, [Burman \(1981\)](#) notes that formal calendars of Simbo, Solomon Islands, were mainly concerned with activities undertaken by men, with many predominately female activities, for example, shellfish collecting, rarely included. It is therefore important to consider gender when collecting seasonal calendar information, particularly as the impacts of climate variability can impact genders differently ([Anderson 2009a,b](#); [Lane and McNaught 2009](#)). Gender inclusiveness was important to the collection of seasonal calendar information in this project with all workshops ensuring both male and female voices were heard. Wherever possible the teams facilitating the community discussions included women, making it possible to have men or women only discussions, and this was seen to increase the comfort and participation level of women in the

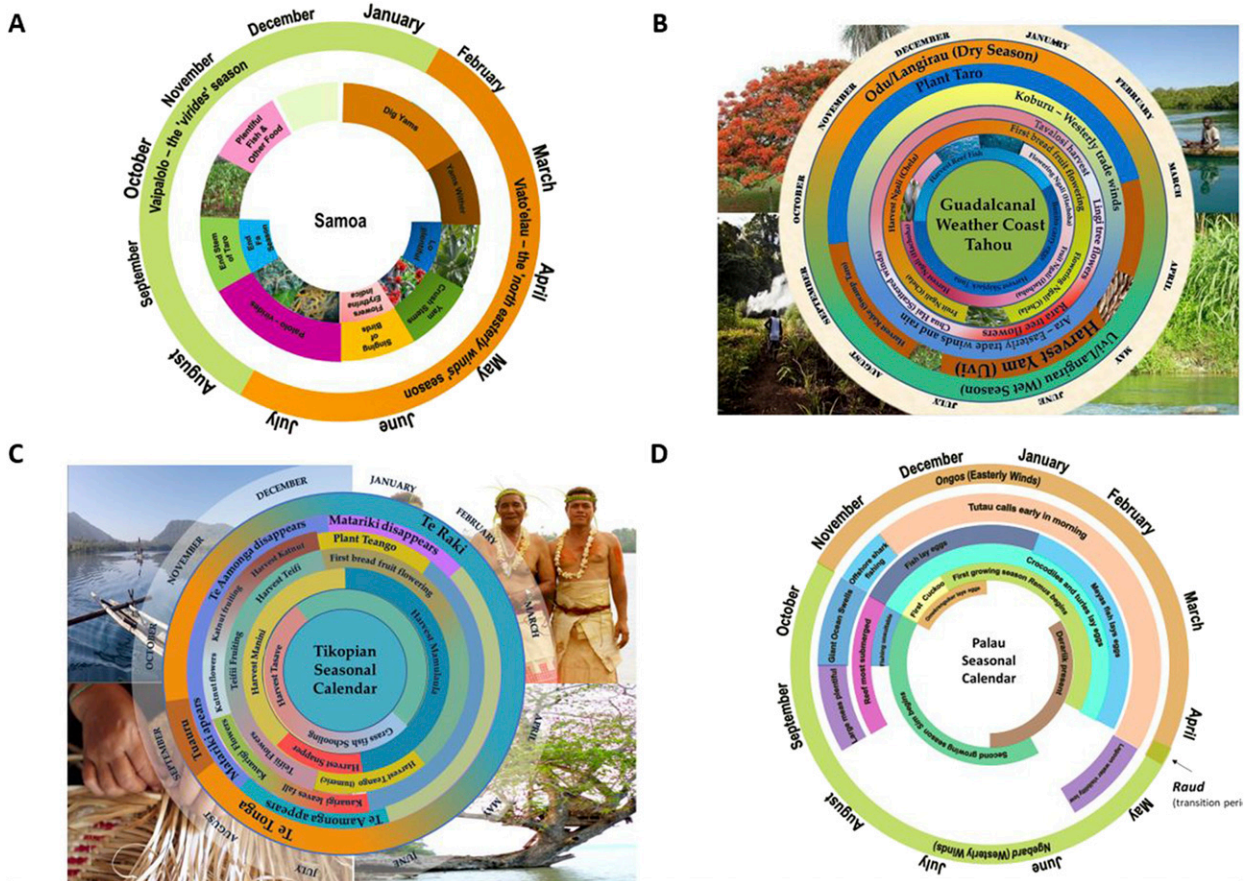


FIG. 2. Example seasonal calendars for (a) Samoa [based on Lefale (2003, 2010)]; (b) the Guadalcanal Weather Coast, Solomon Islands; (c) Tikopian people, Solomon Islands; (d) Palau [based on Klee (1976) and Takeda and Mad (1996)]. Calendars such as these are useful climate communications tools. [The Komu’valu Community contributed the information for the Guadalcanal calendar, and the Nukufero and Somata communities contributed to the Tikopian calendar; (b) and (c) were produced by the Solomon Islands Meteorological Service with permission from the respective communities.]

community [e.g., Solomon Islands Meteorological Services (SIMS) 2015a, unpublished manuscript]. However, gender representation is not always mentioned in the literature on seasonal calendars with little information provided on the gender of the people interviewed (e.g., Collocott 1922; Klee 1976; Mondragón 2006; online supplemental Table S1). At best there are hints that the calendars are built around male knowledge (e.g., “calendar does not propose to say that on such and such day, the men of the community, will be at this particular location doing this particular activity”; Klee 1976; Burman 1981; Pam 2015).

b. Constructing the calendars

Calendars were constructed for select communities (Solomon Islands), provinces (Vanuatu) or nationally (Samoa, Palau, Tonga). In all cases, the first step in constructing the calendars was to define typical seasons, according to local names and expected weather conditions. For example, the Samoan calendar was divided into two main seasons: Vaipalolo and Viato’elau, as was the calendar for the Weather Coast (southern Guadalcanal) in the Solomon Islands: Odu/Langirau, the dry season, and Uvi/Langirau, the wet season (Fig. 2).

The division of the year into at least a wet and dry season is common in the Pacific (this study; Klee 1976; Mondragón 2014; online supplemental Table S1). However, as more and more communities were consulted in the Pacific, it became clear that seasonal calendars were likely to differ when considered across cultural groups or countries (this study; Mondragón 2014). This was particularly true for countries spread over a wide latitudinal range, for example, Vanuatu and the Solomon Islands. For example, even though the seasonal calendars for Guadalcanal and the Tikopian people of Nukufero and Somata in the Solomon Islands both have two main seasons, the names for these seasons differ, as does the timing for the transition from one season to the next (Fig. 2), and the calendar in Keremama et al. (2019). Differences in seasonal calendars for different locations may also be explained by differences in livelihood and therefore familiarity with different environmental indicators (Kassam et al. 2018), for example, coastal fishing communities versus mountain farmers.

During the data collection workshop in Nukufero, Solomon Islands, there was some conflicting information among the four community breakout groups around the occurrence and

definition of the two main seasons, Te Raki and Te Tonga (SIMS 2015b, unpublished manuscript). This confusion may have arisen due to a variety of factors including differences in the climate of the Russell Islands (Central Province of the Solomon Islands), where they are now living, and that of Tikopia, their place of origin, with some community members retaining traditional Tikopian knowledge while others have adapted their knowledge to fit their current location. In addition, some community members may have adjusted their understanding of climate to fit with Gregorian calendars. This blurring of traditional with other calendars, including formal Christian calendars, may be one reason why there was little prior information published on indigenous calendars in the Pacific (Mondragón 2014). Alternative explanations for differences in the Tikopian calendars include possible associations of southeasterly winds with rainfall resulting in two wet periods of the year or the Tikopian understanding of seasons may be less related to rainfall and more related to winds leading to confusion around which are the wet and dry seasons. Two seasons, defined by dominant wind directions, have been described for Pileni Island, which, like Tikopia, is also in the Temotu Province. *Koburu* is the season of west to northwest winds and has typically wetter conditions, occurring November to May, and *Ara* has east to southeast winds and occurs from June to October (McNaught et al. 2011). These seasons have similar, but not identical, timings to the Tikopian calendar and to the seasons described by Keremama et al. (2019). A subsequent workshop on Somata, with two community breakout groups helped to clarify the Tikopian seasonal timing but further research is required into historical and anthropological records for insights into the climate of Tikopia and additional interviews with senior people from Tikopia, who did not migrate to the Russell Islands, may help to confirm traditional seasons. Differences in knowledge systems according to settlement histories has also been reported in central Asia (Kassam et al. 2018).

Once the seasons were defined, the timing of key plant and animal behaviors and cultural activities were documented. Often these related to crop or fisheries species, such as when to plant or harvest. For some species, the timing was relatively fixed from year to year, such as in Micronesia, where the year is separated into yam (*rekenpwel*) and breadfruit (*rekenleg*) seasons (Raynor et al. 2009), whereas for others it varied following the appearance or behavior of another species or phenomenon (e.g., the call of the sandpiper is a cue for the harvest of sea worm at next full moon in Vanuatu; Mondragón 2004 or the movement of the Pleiades across the sky; Mondragón 2014) with the length of the season determined by the “duration of significant seasonal events within that season” (Woodward and McTaggart 2019). Seasonal calendars also have a cultural aspect, with some countries/communities also documenting when culturally significant events occurred, such as the kaloama (*Mulloidichthys flavolineatus*) season and blessing of the yams in Niue and custom harvest ceremonies in Tafea Province, Vanuatu (Fig. 3). In American Samoa, the month of May is sacred because of Fe’e (*Octopus cyanea*), where some coastal villages ban fishing during this time (Western Pacific Regional Fishery Management Council and NOAA 2019).

Seasonal or traditional calendars are based on context-specific relationships between communities and their environment: the land, sea, and climate. Key features of these calendars often relate to food production, for example, fishing, hunting, gardening, or agroforestry, which in turn may be driven by regular changes in dominant wind patterns, temperature (less so in the tropics), ocean currents and wave activity, rainfall, and lunar or astronomical cycles (Green et al. 2010; Mondragón 2014; Kassam et al. 2018). In the Pacific, these seasonal calendars also have a cultural aspect, incorporating ceremonies, rituals, and community activities that are not always related to production or resource management (Mondragón 2014). For example, astrological calendars are used to determine the best time of year to undertake voyages in Micronesia and Palau (Goodenough 1951), whereas Cook Islanders link specific nights in their lunar calendar to the appearance of burial spirits (called *arapō*; Clerk 1990).

For national and provincial calendars, and for communities situated on the coast, a decision was made on whether to create separate calendars for land (agriculture and forestry) and sea-based (fisheries) species and seasonal events or for crops versus noncrop species. Several primary uses have been documented for other seasonal calendars in the Pacific, including for fishing, agriculture and cultural events and it was not unusual for the calendars to focus on only one of these (online supplemental Table S1). For example, the focus of the Palau seasonal calendar, described in Klee (1976), was on fishing, as key cropping species were said to vary little with the seasons. In contrast, many of the calendars compiled for Vanuatu were agricultural, focusing on plants important for food production (supplemental Table S1). It is unclear whether this was due to the villages sampled (which may have been distant from the coast) or the authors’ bias in data collection.

There are many ways in which seasonal calendars can be presented, for example, as descriptive text, lists, or tables or in circular formats (e.g., Green et al. 2010; Johnson 2014; Ulrichs et al. 2015; <http://www.bom.gov.au/iwk/>; online supplemental Table S1). In earlier publications (Table S1) descriptive text was more commonly used to explain seasonal calendars. Between 1950 and the early 2000s, tables often supplemented this text, perhaps due to improvements in the printing process. In more recent decades, seasonal calendars displayed in circular formats became more common in the printed media and on websites (e.g., <http://www.bom.gov.au/iwk/>).

The Pacific NMSs, together with partner organizations and community members, considered the pros and cons of each format for displaying their seasonal calendars. In some cases, the draft seasonal calendars were presented back to the communities in a tabular format (Fig. 3), while in others a concentric circular format was used (Fig. 2). As the circular format better represented the continuous nature of time and the seasons, this was the format preferred for the final calendars.

As literacy levels vary across the region, and within some countries multiple languages are spoken, images (either photographs or drawings), rather than or in addition to text, were used to show the species behavior or seasonal events within the calendars (e.g., Micronesia Conservation Trust 2011; Tualaufale 2015). This approach has been used by others, such

	January	February	March	April	May	June	July	August	September	October	November	December
Climate												
Rainfall (mm)	240	220	340	150	98	90	50	60	20	10	105	100
Temperature (°C)	26.2	26.4	26.2	25.1	23.5	22.5	21.4	21.3	21.8	22.9	24.3	25.4
Hot season (Nov – Apr)												
Wet season (Nov – Apr)												
Cyclone season (Nov – Apr)												
Cold season (May – Oct)												
Dry season (May – Oct)												
Activities												
Harvest of breadfruit												
Tree planting season												
Harvest of namambe												
Harvest of nantau												
Weeding of gardens												
Harvest of nakavika												
Yams ready to harvest												
Planting of citrus												
Good collection of chicken eggs												
Best for flying fish												
Harvest of citrus (orange/mandarin)												
Harvest of sugarcane												
Harvest of nakatambol												
Offerings of best yams and fruits												
Harvest of taro												
Planting of taro												
Hunting for wild animals												
Large yam harvest												
Custom harvest ceremonies												
Planting of taomoto and cabbage												
Find places to make new gardens												
Brushing and cleaning of new gardens												
Trees lose leaves (natavoa, napanga, bluewota)												
Ploughing of the soil												
Yam mounding and planting												
Planting of kumala												
Planting of water taro												
Staking of yam vines												
Planting of yams and banana												
Planting of manioc												
Burning of gardens												
Harvest of sandalwood												
Harvest of mango												
Harvest of banana												
Harvest of manioc												
People seek food in old gardens												
Christmas preparations												
Other Indicators												
Breeding / mating of animals												
Seabirds lay eggs												
Brown and green seaweed common on reefs												
Animals get thin												
Trees gain new leaves (natavoa, napanga, bluewota)												
Food is in short supply												
Flowering of nantau												
Flowering of nakavika												
Animals move towards the bush												
Yellow hornets build nests in homes												
Flowering of namambe												

FIG. 3. Draft seasonal calendar for Tafea Province, Vanuatu, that was provided to community members for verification.

as Rivero-Romero et al. (2016; in Mexico) and for indigenous communities in Australia (www.bom.gov.au/iwk; calendars for the Banbai, Kaurua, Masig, Ngoorabul, Yawuru, and Yirrganydji). Not only does this make the information more accessible, but it can also make it more visually appealing. The use of local language and terms for the events within the calendars was also preferred by participants in this study.

Many authors map the local name for each month with the Gregorian months, even when the traditional calendar is based on lunar cycles and the traditional months and Gregorian months may not fully coincide (e.g., Takeda and Mad 1996; Mondragón 2006). In some cases, it was unclear whether names provided for the months were local names for the Gregorian months or names for traditional “months” (e.g., Lefale 2003, 2010). The practice of relating traditional seasonal calendars

back to the Gregorian one can make it easier for those with limited or no local indigenous knowledge to understand and engage with, but this can lead to the loss of finer details, such as variances in the timing of the start of seasons or months from year to year, due to changes environmental cues (Woodward 2010; Woodward and McTaggart 2019). Similarly, it is important to consider who the target audience is when deciding on the language (indigenous, English, or a mix of both) for the names of seasons, months, phenomena, and species depicted within the calendar (Goldman et al. 2018; Latulippe and Klenk 2020).

A literature review identified that traditional calendars in the Pacific predominantly had 12–13 months per year and were often lunar in origin or had a lunar component to them (online supplemental Table S1). For example, for communities in

Collocott (1922)			Taulaufale (2015)	
Tongan Season	Meaning	Timing	Tongan Season	Timing
Liha-mua	Early nit (little things)	December – January	Lihamu'a	21 December – 21 January
Liha-mui	Late nit	January – February	Tanumanga	21 January – 21 February
Vai-mau	Early rain (water)	February – March	Vaimui	21 February – 21 March
Vai-mui	Late rain	March – April	Fu'ufu'unekinanga	21 March – 21 April
Fakaafu-moui	Putting forth living shoots	April – May	Faka afu mate	21 April – 21 May
Fakaafu-mate	Dead, dying suckers or shoots	May – June	Liha-mua	21 May – 21 June
Hilinga-kelekele	Laying earth (digging yams)	June – July	'Ao'ao	21 June – 21 July
Hilinga-meaa	Laying meaa (dig / store remaining yams)	July – August	Fakaafu-moui	21 July – 21 August
Aoao	(time for cutting yams for seed is over)	August – September	Vai mu'a	21 August – 23 September
Fuufuunekinanga	Full leafiness	September – October	'Uluenga	23 September – 21 October
Ulu-enga	Yellow head	October – November	Hilinga-me'a'a	21 October – 21 November
Tanu-manga	Throwing soil on branch, fork	November – December	Hilinga-kelekele	21 November – 21 December
Ooa-ki-fangongo*	Using coconut shell as basket	(after Tanu-manga)		

FIG. 4. Tongan seasonal calendar according to Collocott (1922) and Taulaufale (2015). Collocott's calendar is based primarily on yam phases, and Taulaufale's is based on astronomy and ancient Tongan political culture. The exact division of the calendar of Collocott is based on plant and animal behavior. The asterisk indicates an extra season that does not occur every year.

Tonga, traditional timing for planting and harvest revolves around moon phases, and this influenced the seasonal calendars (Collocott 1922; Taulaufale 2015), each month starting with the thin crescent of the new moon (Kanongata'a 2011). According to Collocott (1922) some years are divided into 12 months and others into 13 months, depending on observations of yams, and other plants and fishes toward the end of the year. The “months,” and their naming, are based largely on agriculture, but the names also apply to the moons. The phases of the moon also determine the optimal times within a month for regular activities, such as planting and weeding (Kanongata'a 2011) or fishing (Collocott 1922). Taulaufale (2015) however, believes that there are only 12 months in the Tongan year and that the order proposed by Collocott is incorrect (Fig. 4); however, the Tongan Ministry of Agriculture and Food, Forests and Fisheries promotes the calendar of Collocott, with farmers using yam-based calendars (O. Fa'anunu, unpublished material). Traditionally there were two main seasons in Tonga each year, though when these occur is currently unclear (Kanongata'a 2011). A seasonal calendar centered on a single important food source was also observed in Tlaxcala, Mexico (Rivero-Romero et al. 2016). For the agro-festive calendar of El Carmen Tequexquiltla, Mexico, the central component of the calendar is maize, the inner circle showing agricultural activities associated with maize production, with outer circles corresponding to other environmental indicators for that time of year, general weather conditions, and lunar cycles.

The use of intercalation or transition periods appeared in some of the traditional lunar calendars to maintain seasonal synchronicity (e.g., Turner 1884; Collocott 1922; Meggitt 1958;

Roberts et al. 2006), though this practice was not standard for all lunar-based calendars in the region (e.g., <http://what-when-how.com/ancient-astronomy/hawaiian-calendar>; see online supplemental Table S1). Lunar observations are also used in the eastern Atlantic by artisanal fishermen both to locate fishing grounds and for traditional weather forecasting and by locals in Tuvalu to plan traditional agricultural practices (Nakashima et al. 2012).

Traditional calendars are not only related to annual, recurring, or seasonal patterns but can also incorporate weather and climate information over longer, multiyear time scales, for example, El Niño–Southern Oscillation (ENSO)-related periods of drought or wet (Green et al. 2010; Nakashima et al. 2012). Having a local seasonal calendar can also be an effective way of discussing ENSO-related climate variability, and associated activities and preparedness, with communities; for example, in the Marshall Islands, traditional calendars are used to decide when to harvest traditional crops between normal and El Niño years (Pacific Islands Climate Centre 2017). The use of visual climate tools that link community concepts with those of climate have previously been shown to be effective in the Pacific region, for example, the Pacific Adventures of the Climate Crab (<https://www.pacificclimatechangescience.org/animations/climatecrab/>).

Care must be taken when constructing traditional calendars, as Mondragón (2014) rightly points out. Often knowledge is reduced to climate indicators, that is, representing only those parts of the traditional calendars that can be easily understood in scientific-naturalist terms, for example, appearance of the Palolo worm (*Palola viridis*) or flowering of the Narara (*Erythrina variegata*), with the loss of cultural information

and/or local meaning (Mondragón 2014; Goldman et al. 2018). People's understandings and reactions to the same plant or animal climate indicator may differ among communities, and over time, even within the same country (Mondragón 2014).

Kassam et al. (2018) use an iterative process to develop ecological (seasonal) calendars for central Asia. Community participatory approaches were used to identify lists of important species, these were included as indicators if they met the following criteria: "1) known by community members, 2) observable throughout the landscape, 3) occurring in synchrony with livelihood activities, and 4) responsive to climate trends and variability." In our study we were less restrictive, allowing the community to determine which species or activities to include according to what they perceived as important to their community. However, often these indicators met Kassam et al.'s criteria.

c. Verifying the calendars

For the countries involved in this project an important step post development of the initial seasonal calendars was verifying that the information contained within them was correctly captured and displayed. This was achieved by returning to the communities who provided the initial information, in the case of Vanuatu and the Solomon Islands, or consulting with new community members, when verification was of already published (national) calendars, for example, Samoa.

By revisiting existing calendars, such as those developed by Lefale (2010) and Collocott (1922), community members were able to provide insights into aspects of the calendar that may no longer be considered accurate, for example due to environmental changes, or may not have reflected the true calendar at the time, for example, due to interviewing the wrong people, insufficient members of the community, or being misled or misunderstood by the community members consulted, or differences in names and timing of the seasons between communities. For the Samoan calendar of Lefale (Fig. 2) the verification process by community elders found that, although the season *vaiteolau* was associated with wind direction, the origin of the name for the other season, *vaipalolo*, is uncertain. The timing of the palolo season also differed with Lefale (2010) documenting it as July/August and community members as October/November (authors' personal observation). Further community participation, both in groups and as one-on-one discussions, continues to be undertaken in Samoa to better understand the traditional calendar, with participants being selected by the Ministry of Women, Communities and Social Development and based upon their level of TK expertise and ensuring that both men and women participate. For Tonga, once additional funds become available, the TMS plans to extend their community consultations to include to Tonga's northern islands, as the calendars are expected to vary from north to south.

Although some authors recognize some of the issues mentioned above (e.g., Taulaufale 2015), most authors who develop seasonal calendars do not discuss verification of the information collected, that is, they collect information during community visits but do not appear to take the final product back to the community to ensure that it is accurate and

representative. An exception is Woodward (2010), who repeatedly checked and rechecked the indigenous Australian knowledge collected, including the meaning and spelling of words, and that these words were used in the correct context, as were their links with other words and seasons. In Woodward's case, the community decided what knowledge (and images) were to be included in the final calendar.

There may be occasions on which community members may not agree on aspects of the seasonal calendars, for example, names of the seasons or months, when they occur or how they are defined, such as occurred during community workshops in the Solomon Islands (SIMS 2015b, unpublished manuscript). In such cases, it is important to provide time for discussion around any differences, ensuring that participants are given an opportunity to be respectfully heard. Having processes and procedures in place for managing disputes is good practice (Malsale et al. 2018).

Another limitation to collection and verification of seasonal calendar information is the impact of the researcher on the results obtained. Most historical calendars were constructed by researchers from outside that community. As such, unless the researcher is fully immersed in the local culture and has built relationships of trust with the community members, the information captured by the researcher may only represent part of the story. In some cases, the way the research is conducted, including the types of questions asked, may restrict communities from providing the full cultural context of their seasonal calendar. In other cases, some TK may be withheld because of its sensitive nature, as it may only be able to be shared with certain people, for example, according to gender or tribal status (Chambers et al. 2017; Malsale et al. 2018). The collection and verification of seasonal knowledge works best if indigenous people are given a central role in the process (Nickless et al. 2007; Malsale et al. 2018).

d. Using the calendars

With the colonization of nations, many seasonal calendars have been suppressed or lost as part of deliberate efforts to undermine traditional knowledge systems (Kassam et al. 2018). A lack of documentation, with information traditionally being shared orally, has also led to the loss of some knowledge (Green et al. 2010). For example, the movement of younger generations away from their village (e.g., to find work) can result in a loss of cultural transmission as elders pass away. Fortunately, interest is growing among indigenous communities in revitalizing seasonal calendars, particularly as tools for building capacity to cope with climate change (Kassam et al. 2018). Traditional knowledge can be sensitive in nature, and permission should always be sought from the knowledge holders before using the seasonal calendars and the information within them (Woodward 2010; Malsale et al. 2018).

Traditional calendars are an important tool for understanding past environmental changes, including climate variability and change (McNaught et al. 2011; Mondragón 2014). The use of seasonal calendars and their associated traditional knowledge can reduce potential negative effects of climate and natural disasters on agricultural activities, including providing

strategies for dealing with uncertainty and increasing food security (McMillen et al. 2014; Rivero-Romero et al. 2016).

Adaptation to climate change can be facilitated by seasonal calendars because, unlike the Gregorian calendar, many seasonal calendars are not designed to measure time but rather to relate or organize seasonal activities (Green et al. 2010; Mondragón 2014; Kassam et al. 2018); for example, yam leaves changing color marks the time to start burning the bush so that the land is cleared for new growth (Green et al. 2010). Thus a flexibility in the timing and length of the seasons, and associated activities, is related to biological indicators (Green et al. 2010; Armatas et al. 2016; Woodward and McTaggart 2019) and this may assist communities to understand and anticipate new climate variability (McMillen et al. 2014; Kassam et al. 2018). Although there are also concerns that in some locations traditional calendars may no longer work (e.g., eastern Papua New Guinea; Galloway McLean et al. 2011) with significant changes being observed in some of the indicator species (e.g., McNaught et al. 2011). Another concern is the impact of climate change on farming in the Pacific, with the two main seasons (hot-wet and cold-dry) no longer seen as clearly distinct by some (Percival 2008).

An important aspect is that seasonal calendars, as with TK in general, are not static and can evolve over time. It is this feature that gives them continued relevance and longevity (Kassam et al. 2018). An example is the inclusion of the introduced *Narara* (*Erythrina variegata*) into several Vanuatu seasonal calendars (this study; Mondragón 2014), with communities in central Pentecost now using the onset of flowering in this species as an indicator of when to start clearing gardens for the planting season (Wheatley et al. 1992). Using a participatory approach to the construction of the calendars, for example, allowing community members to select which species and activities to include, is likely to increase the adaptive capacity and sustainability of calendar use in the long-term (Kassam et al. 2018).

Communities in Temotu in the Solomon Islands use annual seasonal calendars to document environmental change. Local elders, for example, report less fruiting, stronger and more variable currents, increased sea level inundation events, and changing wind and tidal patterns (McNaught et al. 2011). Historical timelines, or decadal calendars, of past significant climatic and cultural events (e.g., changes in language, tsunamis, or cyclones) have also been documented in these same communities, (McNaught et al. 2011) and show changes to calendars over time. This can help locals to understand how they adapted to past environmental changes. Seasonal and historical calendars are thus a useful tool for Pacific communities to recognize and communicate climate change and resilience, which they can also discuss and compare to the climate records of their national meteorological office. Some NMSs, such as Samoa's, also use seasonal calendars to help with verification of TK stories related to seasonal forecasting. In Vanuatu, community rainfall observers monitor the flowering and fruiting of mango and breadfruit, having identified their usefulness for forecasting tropical cyclone activity while constructing their seasonal calendars. VMGD includes the resulting TK forecast in their tropical cyclone outlook (A. Willy,

unpublished material). Elsewhere in Oceania, Australian indigenous seasonal calendars similarly demonstrate a sophisticated local knowledge of changes in seasonal indicators and climate observations over several years (Green et al. 2010).

Kassam et al. (2018) take traditional seasonal calendars (seasonal rounds in their terminology) one step further in that they combine and test this information against current scientific understanding and observations in order to build ecological calendars that are based on hybrid knowledge. They believe that the resulting ecological calendars will allow for knowledge transfer along bioclimatic gradients and will increase climate adaptation.

Seasonal calendars are a useful tool for traditional climate education and awareness. Although traditional knowledge is highly regarded in the Pacific, younger generations are typically less aware of traditional forecasting methods (Malsale et al. 2018). McNaught et al. (2011) found seasonal calendars useful in a remote region of the Solomon Islands for discussing traditional seasonal indicators, climate change and its impacts, though younger community members were less aware of the traditional knowledge surrounding these. In Vanuatu there is a weekly school program to reengage young students with traditional knowledge that teaches them about weaving, songs, arts and crafts, and the traditional names of flora and fauna. The women fieldworkers involved in the program have also documented the traditional calendar that is now one of the primary tools for teaching culture in schools (Huffer 2006), and the calendars developed under this project will also be used by the NMSs during school visits. Elsewhere, Woodward (2010) found aboriginal elders wanted seasonal calendars developed to enable the information to be accessible to younger generations, including as teaching aids, for example, posters, they could use in local schools, thus promoting intergenerational transfer of knowledge (Woodward and McTaggart 2019) as well as assisting in the revitalizing of traditional knowledge and language.

Seasonal calendars have also been used to demonstrate local presence by indigenous groups, for example, with respect to water usage, and values of aquatic and other systems, and for facilitating meaningful engagement in natural resource management, for example, environmental health and resource availability (Woodward and McTaggart 2019). Thus, seasonal calendars can be used to promote communication across generations, cultures, and languages.

Over the course of the Pacific traditional knowledge projects, it became apparent that the discussions around traditional weather and climate knowledge were greatly valued by the community members. Several elders expressed their appreciation that their knowledge was being recorded for future generations and young and middle-aged participants commented they had not thought to ask the elders about their knowledge. "An old man, in response to a young man's question as to why he had never shared these stories with him, replied, 'you never asked, if you ask I will tell you these stories'" (SIMS 2015b, unpublished manuscript). On another occasion, in a meeting of community leaders and the Vanuatu Meteorology and Geo-Hazards Department, the presentation on provincial calendars was so well received that a chief

wanted to share his village calendar with the group. It is hoped that these Pacific projects will help to revitalize seasonal traditional knowledge, ensuring future generations better understand the interactions between climate, environment, and culture. To assist with this, several of the seasonal calendars produced through this project are prominently displayed in the communities, for example, on community notice boards, in schools, in weather and climate awareness brochures produced by the local NMSs, and as part of World Meteorological Day celebrations. A similar approach to revitalizing seasonal traditional knowledge has been used in Darwin, Australia, where public places, such as a city playground, proudly display local indigenous calendars. Educational resources based on seasonal calendars have also been developed by ABC Education (<http://education.abc.net.au/home#!/media/1771788/indigenous-seasons-across-northern-australia>).

e. Other findings

The initial workshop in the Solomon Islands (held in Honiara in 2014) highlighted the importance of allowing adequate time and having the right people present. Although the information on seasonal calendars collected during the two hours allocated for this task was seen by the participants as useful and a good first draft, it was clear that further community participation was required to complete the calendars (SIMS 2014, unpublished manuscript), as was subsequently done for Guadalcanal, Malaita, and Central Province (Russell Islands).

The collection of traditional knowledge should never be a one-way process, and it is important that during the process that the benefits that the community will receive from sharing their knowledge with others are clearly defined at the outset (Woodward 2010; Malsale et al. 2018). Benefits could include, but are not limited to, conservation of the knowledge for future generations, education of younger generations on environmental interactions and their place in these, contributions to environmental management, and community resilience to environmental change.

4. Conclusions and recommendations

When working with TK, there need to be clearly defined benefits for the community who are sharing their knowledge and any products developed should meet the community's needs (Malsale et al. 2018; Latulippe and Klenk 2020). To ensure that this is the case, it is important that there is two-way feedback (Plotz et al. 2017). In this project this meant that the both the community and the NMS were involved in the development of the seasonal calendars and the community had opportunities to ensure the information was correctly captured and had a say in how the products based on this knowledge were used. The project has resulted in the reinvigoration of the use of TK by highlighting its relevance to current generations. Additional benefits for the community from this project included improved presentation, relevance, and understanding of weather and climate forecasts and warnings, through their incorporation of TK, with increased uptake leading to increased resilience to climate extremes.

In summary, we recommend that those interested in developing and using seasonal calendars do the following:

- Use a participatory indigenous led approach in the collection and use of TK.
- Be inclusive. Gender equality and social inclusion are important because they allow for diversity in the type of TK considered and ensure that the information collected, and ultimately used, is relevant to a broader community.
- Protect the rights of the TK holders.
- Ensure that the information accurately reflects the community's views.
- Have clearly defined community benefits.

Although this project documented many seasonal calendars in the Pacific, there remains much that can be learned, and there is an urgency to do this before the knowledge is lost. In Vanuatu, for example, seasonal calendars were documented at the provincial level. However, it is expected that differences may exist at small spatial scales, for example, for individual islands, at the community level, or according to other factors, such as gender. Further research is required to determine the most appropriate scale for each country. It should also be kept in mind that seasonal calendars are not static and are expected to change over time, as species either appear or disappear and as the climate changes. By working together with their communities to more effectively communicate and understand climate variations, NMSs can play an important role in increasing community resilience to climate variability and extremes.

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Data availability statement. Because of the sensitivity around indigenous knowledge and legal ownership, all original seasonal calendar data requests should be made by contacting corresponding author, Dr. Roan Plotz (roan.plotz@vu.edu.au), and/or the respective author from that country. The results of the literature research on seasonal calendars can be found by examining Table S1 in the online supplemental material.

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