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OVERVIEW

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Traditional knowledge for climate resilience in the Pacific Islands

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Abstract

Pacific Islands, many relatively remote and small, have been occupied by people for more than 3000 years during which time they experienced climate-driven environmental changes (both slow and rapid onset) that challenged human survival and led to the evolution of place-based coping strategies expressed through traditional knowledge (TK). In today's globalized Pacific Islands region, into which western worldviews and global adaptation strategies have made significant inroads, most plans for coping with climate-changed futures are founded in science-based understandings of the world that undervalue and sideline TK. Many such plans have proved difficult to implement as a consequence. This paper reviews the nature of extant Pacific TK for coping with climate change, something that includes TK for anticipating climate change (including climate variability and climate extremes) as well as ancillary TK associated with food and water security, traditional ecological knowledge, environmental conservation, and settlement and house construction that represent coping strategies. Much of this TK can be demonstrated as being effective with precedents in other (traditional) contexts and a compelling plausible scientific basis. This study demonstrates that Pacific Islands TK for coping with climate change has value and, especially because of its place-based nature, should be central to future climate-change adaptation strategies to enhance their uptake, effectiveness and sustainability. To this end, this paper proposes

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specific ways forward to optimize the utility of TK and ensure it has a realistic role in sustaining Pacific Island communities into the future.

This article is categorized under:

Climate, History, Society, Culture > Ideas and Knowledge

Paleoclimates and Current Trends > Modern Climate Change

Assessing Impacts of Climate Change > Observed Impacts of Climate Change

Abstract

Ol Pasifik Aelan, plante oli smol mo oli stap wanwan, oli bin gat man i stap long olgeta blong moa long 3000 yia long wan taem we oli bin go tru long ol jenis long envaeromen long ol aelan ia we klaemet nao i mekem (i tekem ples slo mo kwiktaem) mo hemia i jalenjem laef blong ol man long taem ia mo i mekem se oli statem blong kamap wetem ol fasin blong laef wetem ol jenis ia folem wanem aelan oli stap long hem. Ol fasin ia yumi kolem se "traditional knowledge—TK" long Inglis o tradisinol noledj. Long wol blong tedei long Pasifik Aelan rijen, plante plan blong dil wetem wan fiutja we klaemet jenis i jenisim hem i bes plante long ol save blong saens mo hemia i pusum TK i go long wan saed. Hemia yumi luk from ol tingting blong westen wol mo ol strateji o fasin blong faenem wan solusen blong raon wol adaptesen (olsem wanem blong get yus long hem) i afektem. Plante long ol plan ia i had lelebet blong karemaot from hemia. Pepa ia bae i lukluk long hao Pasifik TK we yumi stap yusum finis i stap dil wetem klaemet jenis, wan samting we i yusum TK long klaemet jenis we bae i kam yet (hemia i minim hao klaemet i stap jenis bigwan mo olsem wanem klaemet i muvmuv i go nogud olgeta) mo tu ol nara TK long saed blong kakae mo wota sikiuriti, tradisonel noledj long saed blong fisikel ples mo ol laef we i stap long hem, konsevesen blong envaeromen, mo setelmen mo konstraksen blong ol haos we i soem hao we yumi stap dil wetem situesen olsem. Plante long ol TK ia yumi save luk se hem i wok gud wetem ol nara (tradisenol) situesen we i stap finis mo luksave mo akseptem tru long ol stadi blong saens. Stadi ia i soemaot se Pasifik Aelan TK i gat valiu long saed blong folem mo dil wetem klaemet jenis, from yumi dil wetem long wanwan aelan, mo hemia i sud kam stamba tingting taem yumi kamap wetem ol solusen blong klaemet-jenis long fiutja, olsem ia yumi save yusum gud samting we i stap finis, i saksesful mo holem taet i stap. Blong kasem hemia, pepa ia i lukluk long ol invesmen we Pasifik TK we ol i niu mo olgeta we i stap long taem naoia. Pepa ia i putumaot ol stret fasin blong folem i go blong yusum mo mekem sua se i gat wan stret mo tru wok blong hem blong holem taet ol Pasifik Aelan komuniti i go long fiutja.

KEYWORDS

climate change, coping, Pacific Islands, resilience, traditional knowledge

A cherar a lokelli/The distant past reveals the distant future

(Palauan saying)

Buddha budhiya log sab jaanat raha/Older people knew it all

(Fiji Hindi saying)

E pala le ma'a 'ae lē pala le tala/Stones decay but stories do not

(Samoan saying)

E tawamudu nodra vuku na qase/The knowledge of the elders is eternal

(Fijian saying)

Lulamu ko nyanyio kale nyo me saiva/We live on the knowledge of our ancestors

(Jorio, Solomon Islands, saying)

1 | INTRODUCTION

Covering almost one third of the earth's surface (Figure 1), the Pacific Ocean is peppered with islands that have been inhabited by people for about 3500 years (Pugach et al., 2021). During this period, Pacific peoples experienced and withstood the effects of climate change, ranging from short-onset extremes and subregional climate variability to longer-term periods of warming and cooling (Nunn, 2007), by developing a range of place-specific adaptive (coping) strategies that formed part of a formidable body of traditional knowledge (TK) (Lee et al., 2020; Vierros & Ota, 2019). Traditional knowledge (TK) in the Pacific represents the accumulated place-based understandings of local residents, commonly communicated orally intergenerationally, about the causes and manifestations of natural phenomena, framed within non-western worldviews, and the optimal ways of responding to their impacts.

Following the globalization of the Pacific Islands region, typically starting with 19th-century colonization, much of the earlier Pacific people's TK became blended with that of migrants from other cultural contexts, its functions within the transformed island societies of the region eventually being widely displaced by global (western-scientific) knowledge. Yet to varying degrees, some TK remains in most island groups where it continues to be utilized for coping with climate variability and has the potential to help their inhabitants cope with climate change (Dutra et al., 2021; Wabnitz et al., 2023).

Many argue that islands and island peoples are disproportionately exposed to climate change, that they are inherently vulnerable, and that their inhabitants need to have their resilience built in order for them to cope with future climate change. We dispute these naïve characterizations, noting that Pacific Island peoples did not survive on islands far from continents for millennia by luck but by design, something articulated through Pacific TK. Conventionally-trained scientists are often innately skeptical of non-western or traditional knowledges, sometimes pejoratively labelling them "barriers" to effective adaptation. In contrast, people in many non-western contexts have an innate skepticism about western science, often regarding the concepts they involve and the languages in which they are usually communicated as "barriers" to effective partnership for adaptation. The optimal way forward in situations where western and non-western knowledges confront each other in this manner appears to be one involving knowledge co-production, utilizing the place-based nature of TK to ground adaptive pathways that are effective and sustainable (Mcleod et al., 2019; Rarai et al., 2022; Westoby et al., 2021).

This review outlines the range of Pacific Islands TK useful for building climate resilience. Section 2 explains why Pacific Island people "needed to cope" with changing climate and weather, Section 3 how Pacific Island people "learned" to do this and Section 4 why some of this knowledge became "forgotten." Section 5 outlines the main types of Pacific TK that evolved to cope with climate change and climate variability. Section 6 explores Pacific TK futures. Most authors of this study are Pacific Islanders and have contributed knowledge and insights to render it as accurate an account of Pacific TK and its potential as possible.

2 | NEEDING TO COPE: CHALLENGES TO SUSTAINABLE LIVELIHOODS IN THE PACIFIC ISLANDS

Owing to its great size, it is difficult to generalize about the climate of the Pacific Basin so that, given that most island groups from which TK is described below are within its tropical and central/western parts, this section focuses here.

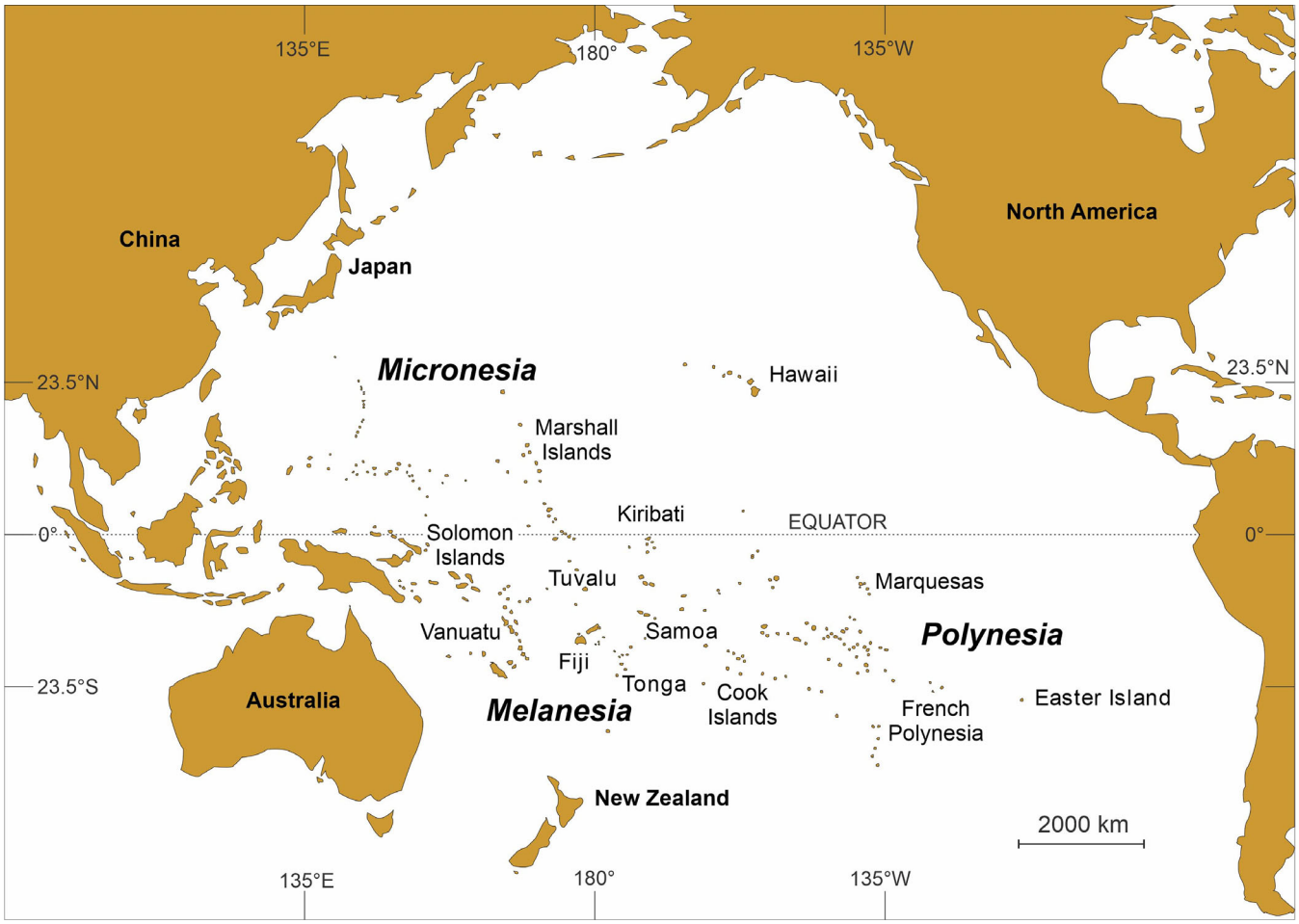

FIGURE 1 Map of the Pacific Basin showing the main Pacific Island groups.

Characterized by easterly air flow and ocean-surface movements, most islands within this subregion experience comparatively little diurnal or seasonal variation in temperature. While seasonal changes in precipitation are common, these become amplified by extreme weather events, especially tropical cyclones (typhoons or hurricanes) and drought. The incidence and amplitude of these are influenced by the El Niño-Southern Oscillation (ENSO) which, together with other interannual climate-ocean phenomena, affected this region throughout its human occupation (Duprey et al., 2012). Most Pacific Island societies developed strategies for sustaining themselves under usual climatic conditions but also sought to "disaster proof" their ways of life for times when their islands were affected by extreme weather. These represent the main reasons why most climate-focused Pacific TK evolved.

The main short-term threat to island livelihoods, especially in the western Pacific, remains the varied impacts of tropical cyclones, especially strong winds, river floods and extreme waves. Reports of cyclone damage from within the past decade illustrate the nature of impacts; these include damage to food crops, pollution/salinization of freshwater sources, and destruction of buildings and infrastructure which together pose enduring threats to human survival (Deo et al., 2022; Neef & Pauli, 2021). Known as the "creeping disaster," prolonged droughts, common during El Niño events in the southwest Pacific, are implicated in widespread livelihood loss (Iese, Kiem, et al., 2021). In the past, some island populations evolved robust ways of coping with such adversity; the example of the "miraculous" survival of the people of Anuta and Tikopia (Solomon Islands) following the passage of Severe Category 5 Tropical Cyclone Zoë in December 2002 illustrates this point and demonstrates the role of TK in such situations (Yates & Anderson-Berry, 2004).

Within the human history of the Pacific Islands, there were also longer-term climate changes that progressively constrained particular practices in particular places, forcing societies to adjust. For example, when most western Pacific Island groups were first colonized by marine foragers in the period 3500–3000 years BP (1550–1050 BCE), the ocean surface in this region was falling from its interglacial maximum level, something that plausibly drove people to settle new islands (Dickinson, 2003; Nunn, 2016). The continuing fall of sea level in the centuries following initial island

settlement placed additional stress on nearshore marine food resources, leading many groups to abandon their dependence on marine foraging in favor of practices better suited to planting crops (Nunn & Carson, 2015). The "AD 1300 Event" (approximately 1250–1350 CE) that was characterized by cooling, increased storminess, and sea-level fall provides another example of a longer-term climate change in the Pacific Basin. This event likely disrupted most Pacific Island societies, forcing the abandonment of coastal settlements in favor of upland, inland or offshore ones in fortifiable locations, and marking the start of a period of conflict and societal unrest that lasted several hundred years (Field, 2008; Nunn, 2007; Nunn, Nakoro, et al., 2022).

3 | LEARNING TO COPE: PRE-GLOBALIZATION RESILIENCE BUILDING IN THE PACIFIC ISLANDS

Over the past two decades, the human history of the Pacific Islands has become more realistically framed as a story of human adaptation to shifting environmental baselines (Nunn, 2007) rather than one of humans manipulating unchanging island environments (Kirch, 1984). This section reviews how Pacific Island peoples "learned how to cope" with climate-driven environmental changes; the next explains how they "forgot" much of the associated knowledge following the societal disruptions associated with foreign settlement, colonization, and their incorporation into a globalized world.

Following initial settlement, Pacific Islanders soon came to understand the limitations of island environments and adapted accordingly (Braje et al., 2017; Kirch, 2007). Learning to cope was forced by the will to survive and the conspicuous lack of other options (compared to continental situations) beyond simply staying within your island group and utilizing the resources available there to support growing populations (Kennett et al., 2006; Kirch & Rallu, 2007). Sustainable production systems developed, exemplified on land by "ridge-to-reef" systems, as once found in Hawaii, Palau and Solomon Islands for example, and under water by declarations of no-take (taboo) zones to conserve marine resources like the *raui* of the Cook Islands, the *mechen* of Micronesia, and the *noho* of Vanuatu (Golbuu et al., 2011; Johannes, 1978; McCoy & Graves, 2010; Mcleod et al., 2019; McMillen et al., 2014; Rantes et al., 2022; Wilmot et al., 2022).

Constraints associated with island living also led to the development of mutual support networks, exemplified by the *sawei* exchange network that operated during at least the last millennium within Micronesia (Figure 2a) and the Lovoni Interaction Sphere during the Lapita-era (approximately 3100–2500 years BP) in Fiji (Figure 2b). These networks, kept alive in clan relationship terms across the Pacific Islands region today (Kabutaulaka, 2015), were primarily for exchange of (needed) valuables and technologies but also served to renew relationships and promises of mutual support should a need arise (Campbell, 2015; Weisler, 1997). Thus if one island (group) was impacted by a disaster and its neighbors were not, the former might be aided by the latter as needed. In Micronesia, for example, "island communities accommodated to climate extremes and natural disasters through the development of social and political linkages between the more vulnerable coral atolls and the neighbouring high islands" (Rubenstein, 2001, p. 75).

Pacific peoples developed a range of place-based strategies intended to align livelihoods with both seasonal environmental changes and those that occurred less regularly but had potentially disastrous impacts. This extended to non-climate events such as earthquakes, volcanic eruptions and tsunamis although there is evidence that the impacts of these extreme/infrequent events were sometimes normalized within trajectories of societal development rather than being the "disasters" they are commonly labeled today (Calandra, 2020; Galipaud, 2002).

4 | FORGETTING HOW TO COPE: EFFECTS OF GLOBALIZATION IN THE PACIFIC ISLANDS

The first half of the 19th century in most Pacific island groups saw profound and enduring societal changes linked to the arrival of outsiders and outside influences, colonization and nascent globalization. In particular, the introduction of unfamiliar diseases (especially influenza and measles) to which Pacific peoples had no natural immunity caused many deaths (Penman et al., 2017), especially of traditional knowledge-holders. This up-ended Pacific societies leaving them more disposed than might otherwise had been the case to cede power to external forces, both secular and religious (Campbell, 2011; Weir, 2014). The subsequent loss of much Pacific TK helps explain the 20th-century identity crises, marked by increased dependency and lowered autonomy, that seeded the impression that Pacific Island peoples are innately "vulnerable" to climate change and lack the "resilience" needed to cope with its growing impacts (Lewis, 1999; Pelling & Uitto, 2001). Such sentiments are often echoed today by Pacific Island leaders who regard "the threats of

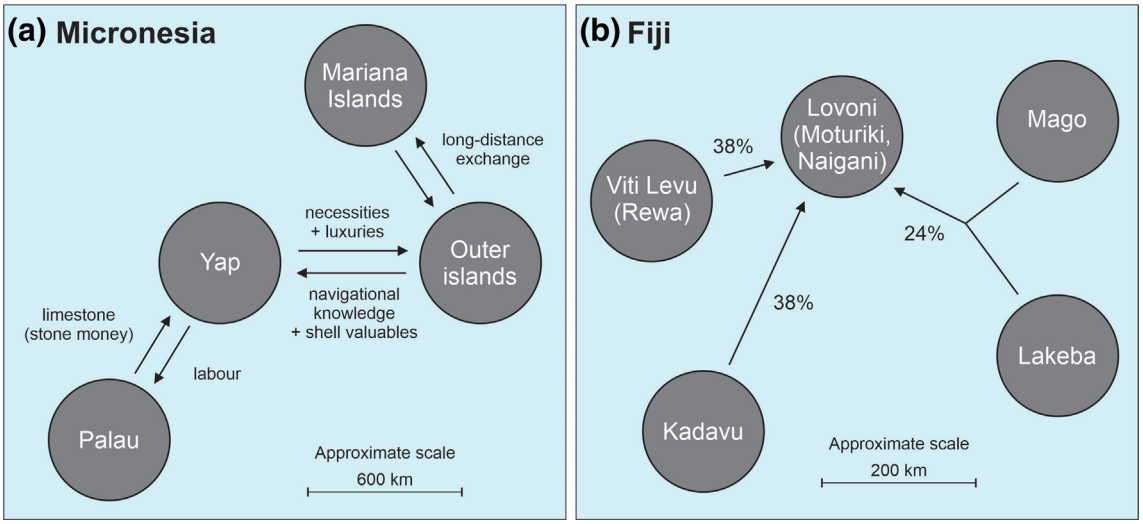

FIGURE 2 Regular inter-island interactions were vital to sustaining island people's livelihoods in pre-globalization times, especially for the supply and exchange of desirable goods but also to maintain kin relationships that would support disaster-affected groups. (A) The *sawei* exchange network in Micronesia showing examples of goods exchanged or rendered in tribute across distances of sometimes hundreds of kilometers of open ocean (after Fitzpatrick, 2008). Most records suggest the *sawei* operated during the last millennium. (B) The Lovoni Interaction Sphere in Lapita-era Fiji (3100–2500 years BP) is inferred to have been a cross-ocean support network, the one-way strength of which is here measured by percentages of exotic sand temper found in pottery on Moturiki Island, part of the Lovoni Volcano (after Kumar et al., 2021). Either the pottery or the temper sand was imported to Moturiki from these places.

climate change and sea-level rise as the defining issue that imperils the livelihoods and wellbeing of our peoples and undermines the full realization of a peaceful, secure and sustainable future for our region" (Report from the 51st Pacific Island Forum Leaders Meeting, July 2022: Item 40). Yet such expressions of need and helplessness are rarely matched at community level in the Pacific islands (Farbotko & Lazrus, 2012), especially where TK continues to be used to support livelihoods (Baru Conservation Alliance, 2022; Basel et al., 2020; Le De et al., 2018).

Compared to the situation a few hundred years ago, Pacific TK is today much reduced in extent and depth. Yet there are parts of the region where TK has survived largely intact. From an outsider perspective, these places tend to be "remote" and often located on "outer islands" in archipelagic contexts or higher inland areas, places where globalized knowledge and practice has found it difficult to take root (Baru Conservation Alliance, 2022; Johnston, 2014; Rantes et al., 2022). In the last decade, there has been a revival of traditional knowledge in the Pacific Islands and a growing acknowledgement of both its utility and cultural acceptability (Kitolelei et al., 2021; Korovulavula et al., 2020; Tui & Fakhruddin, 2022; Wilson & Forsyth, 2018; Winter et al., 2020). In addition, the experience of COVID-19 led many Pacific peoples to return to their rural roots where they learned to re-value traditional knowledges and practices (Iese, Wairiu, et al., 2021; Movono et al., 2022).

5 | TRADITIONAL KNOWLEDGE FOR CLIMATE RESILIENCE IN THE PACIFIC ISLANDS

This review focuses on Pacific TK used for coping with climate change and climate variability, something that is not straightforward to define, especially in contexts like many in the Pacific Islands region where spiritual worldviews often dominate western-scientific ones and where views of which phenomena are (and which are not) plausibly attributable to climate change are not always as clear as elsewhere (Lauer & Aswani, 2009; Luetz & Nunn, 2021). In many rural Pacific Island contexts, "climate change" has often been used as an umbrella concept to explain virtually every deleterious change that occurs when more likely causes are related to globalization and short-term variations in weather (Duvat, 2019; Nef et al., 2021). This situation is compounded by the difficulties of properly translating the concept of "climate change" into languages that never evolved to accommodate such terms, an issue not confined to the Pacific (Kelman, 2018; Rudiak-Gould, 2012).

There is also the question of how to identify TK for climate-change coping. While some of that TK may be clearly focused on climate change (including climate variability), much more refers to coping with environmental-climatic

variations more generally and often targets other livelihood-associated practices. To this end, we recognize three tiers of domains relevant to climate change in Pacific Islands TK. These are shown in Figure 3 and form the basis for the discussion in the rest of Section 5.

Tier 1 constitutes TK focused on climate change and climate variability, including the anticipation or prediction of particular weather-related phenomena. Tier 2 represents TK with a high degree of application to climate change/variability but which also focuses on other aspects of livelihoods, namely "food and water security," "traditional ecological knowledge," 'environmental conservation' and "settlement and house construction." Tier 3 represents TK with some relevance to climate change/variability but which is clearly focused elsewhere, such as in the realm of health and seafaring; Tier 3 TK is not discussed in this review.

5.1 | Pacific TK focused on climate change/variability (Tier 1)

Most extant Pacific TK related to climate variability is that which guides people's interactions with the natural environment, typically optimal times to plant and harvest and fish (Section 5.1.1). Yet much extant Pacific TK is focused on predicting short-term climate variability, especially extreme events such as tropical cyclones and drought (Section 5.1.2). Some possible TK for longer-term coping with climate change is reviewed in Section 5.1.3.

5.1.1 | TK for regulating environmental interactions

In all Pacific Island groups there are bodies of TK that govern (or once governed) people's interactions with the natural environment ensuring, as far as possible under usual weather conditions, that food production would be sustained. For this to happen, Pacific peoples became acute observers of the natural environment and the routine changes it underwent, ranging from astronomical and seasonal changes to more precise annual (biorhythmic) events. For example, among the evidence for the long-term observation of winds and waves in the Pacific region, we cite the catalogue published for Samoa that identified 10 named wind types (Lefale, 2010) and that for northern Pentecost Island in Vanuatu that recorded the same number of cloud types, each used by local residents to infer particular weather changes (Rarai et al., 2022). One of the commonest biorhythmic events in the tropical Pacific is the shallow-water spawning of the *palolo* worm (*Palolo viridis*), which occurs every November or December in the tropical southwest Pacific, about 8 days after the full moon; these events recur every 12–13 lunar months (Caspers, 1984; Johannes, 1981).

The chronometrics of these diverse types of TK can be captured in "seasonal calendars" (Chambers et al., 2021). Most of these calendars were lunar controlled, commonly anchored in localized biorhythmic events, and marked times to plant, harvest or access key resources. For example, throughout the islands of Vanuatu, a well-known such event was the flowering of *narara* (*Erythrina variegata*) "when reef fish, crab and lobster are said to be full of fat. This time is also known to be best for catching octopus, which are said to come out of their holes to see the bright red *narara* flowers" (Hickey, 2006, p. 14).

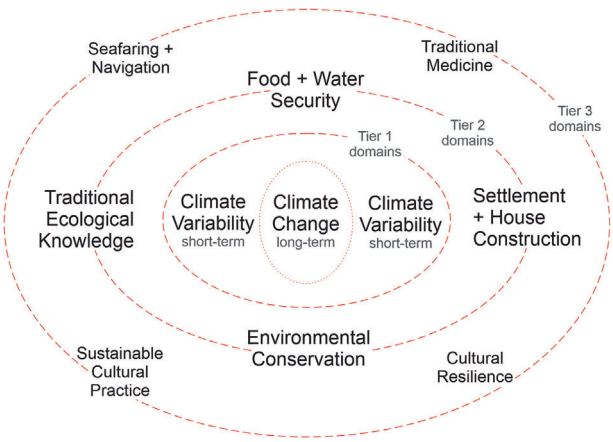

FIGURE 3 Domains of traditional knowledge in the Pacific Islands and their relevance to climate change and climate variability.

It is important to emphasize that these calendars made sense only with lunar changes and have proved challenging to reconcile with the Gregorian calendar (McMillen et al., 2017). For example, residents of Palau (northwest Pacific) anchored their lunar year with the egg-laying of the *kotikw* (*Gerres oblongus*), a type of mojarra (fish), on the new moon of the first month of *ongos* (typically late October–November), an event that has a 29-day imprecision in the Gregorian calendar (Johannes, 1981). Some seasonal calendars in traditional contexts are becoming less accurate, plausibly as a result of climate change (Kassam et al., 2018; Kolawole et al., 2014).

5.1.2 | TK for predicting climate change/variability and extreme weather events

There is considerable information from the Pacific Islands about TK for "predicting" climate change/variability and extreme weather events, so this subsection focuses on this under three categories—animal, plant, and oceanic-atmospheric-astronomical. By far the majority of published information about climate-linked Pacific TK refers to the prediction of tropical cyclones or uncommonly prolonged/heavy rain, so this account concentrates on this. To reduce repetition, this part of this review, summarized in Supplementary Material 1, focuses on five Pacific Island countries—Fiji, Samoa, Solomon Islands, Tonga and Vanuatu.

Much of the Pacific TK described is paralleled elsewhere, suggesting its identification in the Pacific Islands is consistent with that in better-documented contexts, some identified below, which provides a strong argument for further in-depth documentation of extant Pacific TK. Also below are selected accounts of recent scientific explanations of particular TK.

Animal

Avian behavior in the Pacific Islands is commonly interpreted as augural with regard to weather changes. In Tonga, when the *lofa talamatangi* or frigate bird (*Fregata* spp.) is seen to be flying across the land—unusual behavior for an ocean species— this is interpreted as a sign that a tropical cyclone is developing/approaching, a piece of TK captured in the logo of the Tonga Meteorological Service (see *Graphical Abstract*). Similar birds in Fiji are considered *manu-ni-cagi* ("wind birds") and are recognized throughout the archipelago, a role filled in northern Vanuatu by the *mansiroboe*, the black-browed albatross (*Thalassarche melanophris*) (Johnston, 2015; Rarai et al., 2022). There are suggestions from local knowledge holders in the Pacific Islands that these documented uses of avian TK represent only a fraction of what remains known and utilized in some communities, similar to those described below.

Insect (especially ant) behavior in the Pacific Islands is also observed and used to predict wet weather; fruitflies and cockroaches (which probably arrived on most islands only a few hundred years ago) and cicadas serve comparable roles on some islands (Chand et al., 2014; Granderson, 2017). Other animal behaviors are used as predictors of wet/cyclonic weather: for example, in Samoa, when hermit *crabs* (utilized as bait) dig their holes deeper than usual (Lefale, 2010) and in Vanuatu, when *turtles* lay their eggs further inland than usual (Chand et al., 2014).

One of the most widespread types of TK for the longer-range (months rather than weeks and days) prediction of uncommonly wet "wet seasons," likely involving in most instances more tropical cyclones than in a "normal" year, is the observation that within dense vegetation *hymenopterans* (bees, wasps, hornets) build their nests/hives close to the ground rather than higher up (as usual) in the branches of trees. The Kwaio people of Malaita Island (Solomon Islands) say that at such times these insects "behave just like ants," but if no cyclone is forthcoming then they behave "as they should." One report from Fiji suggests this type of nest-building occurs up to 3–4 months in advance of a tropical cyclone, something that leads local residents to make appropriate preparations like storing food (Johnston, 2015; Nakamura & Kanemasu, 2020; Singh et al., 2020). Unpublished observations from Vanuatu show that nest height for some pigeon species is also used to predict cyclone activity.

Comparable accounts of faunal TK come from the Philippines, where hymenopteran hive-building behavior is deemed a sign of flood or strong winds, as is unusual crab and other animal behavior (Galacgac & Balisacan, 2009). In tropical Africa, cicadas (*nyenze*) start "singing" a few weeks before the start of heavy rains (Muguti & Maposa, 2012). Singing crickets are also signs of "danger" in the TK of the Arandic people of Central Australia (Turpin et al., 2013, p. 11) and are used to predict rain in Mizoram in India (Chinlampianga, 2011). When cockroaches (*k'uuruch*) "flutter around the houses" in Yucatán (Mexico), rain is expected within 3 days (Camacho-Villa et al., 2021). Ant behavior is also an important element of African, Indian and Mayan traditional weather forecasting (Chinlampianga, 2011; Ebhuoma & Simatele, 2019; Sethi et al., 2011).

The (unexpected) appearance of migratory birds is commonly employed as an indicator of seasonal change (Agbodan et al., 2020; Yang et al., 2019); in Zimbabwe, the appearance in summer of *chochomela* and *kwarakwara* birds is a sign of a "good" rainy season to come (Jiri et al., 2015, p. 107); in Uganda, the white-browed coucal (*Centropus supercilious*) is the most dependable bio-indicator of the onset of the rainy season (Nkuba et al., 2020, p. 217). In central Australia, where rain is irregular and not seasonal, harbingers of rainfall include sightings of the channel-billed cuckoo (*Scythrops novae-hollandiae*) which is said to "pull" rain clouds into the area (Turpin et al., 2013, p. 24). A "rain-inducing bird" is described in the lore of the Solega people of southern India (Agnihotri & Si, 2012).

It has become clear that certain *bird* behaviors, especially hazard-avoidance behavior, are controlled by infrasound (acoustic waves traveling at frequencies <20 Hz, inaudible to humans) and include those associated with storm avoidance (Bedard, 2021). A seminal study showed how in April 2014 from thousands of kilometers away golden-winged warblers (*Vermivora chrysoptera*), a long-distance migrant bird species, effectively circumvented tornadoes in the southern USA, plausibly as a result of infrasound detection; "birds can detect changes in intensity and Doppler shifts in infrasound, suggesting they can sense the movement and direction of severe weather systems from great distances" (Streby et al., 2015, p. 100). Another study, which included data on frigate-bird movements in the southwest Pacific, concluded that "seabirds appear to be able to circumvent cyclones but use avoidance behaviours only when a cyclone is relatively close and likely when they perceive a wind strength and direction that is indicative of the movement of the cyclone and its heading" (Weimerskirch & Prudor, 2019, p. 7). Such explanations are consistent with TK of avian behavior in the Pacific.

Studies of *wasp* nesting behavior during variable climate conditions in French Guiana conclude that the ability of these hymenopterans to quickly move their nests to more sheltered locations "may represent an adaptive trait that is crucial for epiponine wasps in exceptionally wet years" (Dejean et al., 2010, p. 39).

Thanks to thermo-sensitive neurons in their antennae, *ants* are able to change their behavior as temperature changes (Ruchty et al., 2010) but more recently it was discovered that ants appear able to "evaluate changes in local conditions over time" (Hart et al., 2018, p. 887). Similarly, by being able to sense relative humidity changes, leaf-cutter ants may be able to "detect small environmental changes that predict rain and respond to them in adaptive terms" (Farji-Brener et al., 2018, p. 238). Although this does not "scientifically prove" that ants can detect tropical cyclones days in advance, it does certainly increase the possibility that ant behavior is predictive in ways explained by Pacific TK.

Plant

Of the numerous floral predictors of unusually wet weather, sometimes explicitly tropical cyclones, in Pacific TK, one of the most widespread is the anomalously excessive or early *fruiting* of particular species. This is especially common with breadfruit (*Artocarpus* spp.) that is said to grow in abundance, specifically to grow in bunches (>3 fruits) along a single branch rather than the usual 1–3 fruits per branch; a similar phenomenon is reported for mangoes (*Mangifera indica*) (Janif et al., 2016; Johnston, 2015; Korovulavula et al., 2020; Nakamura & Kanemasu, 2020). A comparable sign is when various plants fruit outside their normal season, often 1–2 months earlier than usual; this is known for mango and for rose apple (*Syzygium malaccense*) (Chand et al., 2014). Common signs of impending wet weather are found in the *shooting* behaviors of bamboo (generally *Bambusa vulgaris*) and plantain (*Musa* spp.) in the Pacific Islands; bamboo shoots grow "suddenly" while the central shoot of the plantain, which normally grows straight, will be conspicuously curled (Janif et al., 2016; Nakamura & Kanemasu, 2020).

While some of the indicators of heavy rain discussed above can also be interpreted, typically in a reversed form, as signs of prolonged dry conditions (*drought*), much less published evidence of this exists. In Vanuatu, the wilting of the shrub *diadia* was used to predict the 1997–1998 drought while observations of the growth rates/extent of moss on large trees is also considered augural (Chand et al., 2014; Rarai et al., 2022).

Traditional phenological indicators of future weather are common in many parts of the world (Acharya, 2011; Chisadza et al., 2013; Nedelcheva & Dogan, 2011). Earlier-than-usual *flowering* of key tree species (*umtopi* and *mopane*) in Zimbabwe are traditional signs of a "poor" rainfall season to follow, even drought (Chisadza et al., 2013). In Botswana, early fruiting of key shrubs indicates low rainfall in the forthcoming wet season (Kolawole et al., 2014). In Manipur (India), the flowering pattern of agave (*Agave cantala*) is used to predict storms (Singh, 2011) while in Tripura this role is taken by night-flowering jasmine (*Nyctanthes arbor-tristis*) (Acharya, 2011). The notion that tree leaves respond to increasing humidity is also captured in the popular western farmers' adage "when leaves show their undersides, be very sure rain betides." Similar sentiments are expressed by Ugandan farmers; "when the rains are going to

start, the flowers of coffee blossom and fall off...when the rains are on set, the coffee beads will wither but when it wants to rain, the coffee will look nice and show signs of flowering until the rains come" (Nkuba et al., 2020, p. 217).

While no parallels are known to the much quoted use of excess/early breadfruit *flowering* as a sign of forthcoming cyclones in the Pacific Islands, there are numerous parallels with mango. For example in Manipur, if mango trees produce "extraordinarily large numbers of flowers/inflorescences, the current year may have more wind/storms and heavier rainfall" (Singh, 2011, p. 191). In contrast, excessive fruiting of mangoes in Zimbabwe portends a rainy season with below-average precipitation (Muguti & Maposa, 2012). The unusual shooting of bamboo is also noted as a phenological precursor of heavy rain in the Philippines (Galacgac & Balisacan, 2009). Among the Sumi of India, an abundance of bamboo flowering shows that a drought will develop yet, if bamboo shoots rise higher than the parent, this heralds above-average rain for the coming year (Sumi, 2018). A link between bamboo flowering and drought prediction is also known in Manipur (Singh, 2011) and is common throughout much of southeast Asia (Jha & Jha, 2011).

Nyctinasty (repetitive flower closure) is a feature of many flowering *plants* but its function is unclear (Minorsky, 2019; Prokop et al., 2019). One possibility is that repetitive closure protects a plant's reproductive organs from approaching extreme weather (van Doorn & Kamdee, 2014), something that could also be extended to leaf behavior, specifically foliar nyctinasty. If this is correct, then this may provide endorsement of the efficacy of the Pacific (and other) TK related to leaf behavior.

While questions remain about climatic triggers of (excess) flowering in mango and other flowering plants (Luo et al., 2019), recent research has identified numerous plausible explanations for associated Pacific TK. For maximum fruiting, mango needs a well-defined winter dry season following one with high heat accumulation during the period of flowering and fruit development (Bally, 2006). Rain and high humidity during flowering and fruit development result in reduced yields due to the development of fungal diseases that cause flower and fruit drop. For breadfruit, it is well known that yield is reduced in cooler conditions while rainfall also reduces flowering (Rajendran, 1991).

Oceanic, atmospheric, astronomical

Wave and *wind* TK in the Pacific Islands is generally site-specific so difficult to generalize about. Residents of Druadrua Island (Macuata, Fiji) interpret breaking waves to predict a cyclone as much as 1 month before it hits while the people of 'Uiha Island (Ha'apai Islands, Tonga) note changes in the shape of the waves. As one Tongan informant said, "There's nature telling us to get ready, something will happen in the future" (Johnston, 2015, p. 6). In the Torres Islands (Vanuatu) there are 13 phrases to describe the state of the tide, including anomalies that herald uncommon events (Mondragón, 2018). In Samoa, where a common aphorism is *ua 'afa le aso* (stormy weather today, perhaps therefore "a day for plaiting *afa*" [coconut fiber rope]), 10 types of wind are recognized in traditional lore (Lefale, 2010). Those indicating the (imminent) arrival of heavy rain, possibly a tropical cyclone, are the winds that blow from the east (*matā 'upolu*), the north (*mātū*) or south (*tuā'oloa*); the latter is feared most, often called a "bad wind" that will cease only when its quota of deaths has been met.

Associated with this are environmental predictors of flood, such as that used by residents of Natawa Village (Fiji) where the water level relative to a river-bank rock is a reliable indicator of when the downstream town of Nadi will flood.

Pacific TK involving *atmospheric* phenomena is also widespread. Several communities in Fiji state that "no clouds in dark blue sky" signals the arrival of a tropical cyclone within a week or more. Other signs are the unusually rapid cloud movements, the observation of "short rainbows," and the appearance of distinctive cirrocumulus clouds known to the people of Waikubukubu Village (interior Viti Levu Island) as *ketetenibici na lomālagi* or clouds that resemble the stomach markings (*ketekete*) of the buff-banded rail (*bici* or *Gallirallus philippensis pelewensis*) in the sky (*lomālagi*) (Johnston, 2015; Korovulavula et al., 2020; Nakamura & Kanemasu, 2020). The appearance of the moon is also augural in several contexts. In Vanuatu, for instance, when the moon is observed to be surrounded by a halo, this is a sign of imminent rainfall (Chand et al., 2014).

Like the Pacific Islands, traditional weather forecasters in the Philippines utilize TK involving observations of unusual clouds and rainbows (Galacgac & Balisacan, 2009). Common are observations of a "long parallel band of feathery clouds" as a precursor of a tropical cyclone (typhoon) or flood. Observations of an incomplete/short rainbow are interpreted as a sign of upcoming rain. The appearance of the moon with a halo (or corona) is also a well-understood sign of imminent rain, often a storm, in many traditional contexts (Camacho-Villa et al., 2021; Jiri et al., 2015; Muguti & Maposa, 2012). In drought-prone Ninh Thuan province in Vietnam, a common saying is "*Trăng quầng thì hạn; Trăng tán thì múa*" or "Corona around the moon, there will be a drought year; Halo around the moon, rain soon" (Huy & Shaw, 2008, p. 80). Changes in *wind* direction as a harbinger of imminent weather changes are well understood

in many cultures, including the Shona of Zimbabwe and the Gabra of Ethiopia (Dejene & Yetebarek, 2022; Muguti & Maposa, 2012).

Changes in the usual patterns of *waves* can be readily explained by the fact that distant storms can drive (long-fetch) ocean swells onto coasts long before the storm winds/rain arrive. Observed changes in *clouds* and *winds*, often unexpected and therefore potentially diagnostic/augural, have long been recognized as "predicting" the development and arrival of tropical cyclones (COSPPac Team et al., 2018; Terry, 2007). Rainbows are sometimes incomplete because they are partly obscured by a distant rain shower. Lunar halos commonly result from the presence of high thin cirrus clouds, signs that storms are nearby; these clouds contain ice crystals through which moonlight is filtered, creating a halo. There are robust scientific explanations for this Pacific TK.

5.1.3 | TK for coping with interannual and longer-term climate variability

There are hints in Pacific Island TK and cultural practice that in the pre-globalization past, Pacific peoples were able to read the signs of *interannual and longer-term* climate variability attributable to ENSO. This is implicit in inferential studies of Pacific Island colonization which suggest that eastward-migrating colonizers recognized and took advantage of El Niño (ENSO-negative) events, when the dominant easterlies became subdued, to sail east in search of new lands, confident that when the El Niño ended, the renewed easterlies would carry them back to their home bases in the west (Anderson et al., 2006; Duprey et al., 2014). It is possible that long-distance cross-ocean exchange like the *sawei* (see Figure 2a) and Kula Ring (Damon, 2017) in the post-settlement Pacific Islands were also aligned with favorable ocean conditions recognized by the onset of an ENSO (+/−) event. This suggestion is supported by evidence of modern traditional practice dependent on an understanding of ENSO variability; in the Torres Islands of Vanuatu, for instance, there may be "a unique form of synchronization between ritual activity and El Niño Southern Oscillation (ENSO)-related (seven to eight year) periods of drought and extreme rainfall" (Mondragón, 2004, p. 33).

5.2 | Pacific TK relevant to climate change (Tier 2)

As shown in Figure 3, there is a second tier of Pacific TK that supports sustainable responses to climate change/variability but is not focused on it exclusively. Such TK serves other purposes associated with sustaining life on islands in the Pacific Ocean, including food and water security (Section 5.2.1), an understanding of island ecosystem diversity and functioning (Section 5.2.2), resource conservation (Section 5.2.3), and the optimal design of settlements and houses (Section 5.2.4).

5.2.1 | TK for climate-impacted food and water security

On many Pacific islands, especially those with comparatively small land areas and/or low elevations, the availability of fresh water for human consumption and plant irrigation in particular is key to island habitability. Many "mystery islands" of Polynesia, uninhabited when first documented yet showing signs of earlier settlement, are likely to have been abandoned because of prolonged water shortage (Anderson et al., 2000), a practice continued in the Marshall Islands within living memory (MacDonald et al., 2020). This also explains why many Pacific Island peoples developed water-conservatory techniques, ranging from the common pond fields, irrigation and terracing (McCoy & Graves, 2010) to more island-specific techniques. For example, prior to globalization, the people of the atolls in the Marshall Islands practiced "a culture of austere water usage" (MacDonald et al., 2020, p. 6) including the use of hollowed-out bases (*emmak*) of coconut trees to store rainwater dripping off the foliage above. More than a millennium ago, the people of Aneityum Island (Vanuatu) created "very sophisticated and spectacular irrigation and water-diversion channels ... to supply the expanding terrace garden system" (Bedford, 2018, p. 12). There is evidence that Pacific peoples favored drought-resistant crop species and evolved techniques to reduce evapotranspiration (Mcleod et al., 2019).

The relative isolation of many Pacific islands encouraged the development of sustainable methods of food production, what have been termed agroecological "structures of permanence" (Clarke, 1977) that provided a diversity of foods and were minimally risk exposed. For example, on northern Pentecost Island in Vanuatu, "the planting of a diverse

array of disaster resilient crops including wild yam (*Dioscorea nummularia*), domesticated yam (*Dioscorea alata*), Fiji taro (*Xanthosoma sagittifolium*), sweet yam (*Dioscorea esculenta*), wild taro (*Alocasia macrorrhizos*), and sweet potatoes is essential to ensuring households and villages possess secure food sources despite variable environmental conditions" (Rarai et al., 2022, p. 17).

The use of agricultural terracing, typically for taro cultivation (Figure 4), is a good example of how Pacific peoples once ensured a steady supply of staples while utilizing steeplands and maximizing the use of available water (Atsiaya et al., 2019; Kuhlken, 2002); similar arguments apply to the use of raised fields in lowland areas to create perched freshwater lenses and enable crop growth on what might otherwise have been unusable land (McCoy & Graves, 2010; Rehuher-Marugg & Tellei, 2011). Adaptive agriculture of this kind is a hallmark of most high-island Pacific societies (Falanruw, 2018; Iese, Wairiu, et al., 2021; Sisifa et al., 2016).

Many foods were bulk-stored in pre-globalization Pacific Island contexts; examples range from matured crops left in the ground to the use of "yam houses" in diverse island contexts, from the atolls of Tokelau and the northern Cook Islands to many parts of high-island Melanesia (Campbell, 2006; Malinowski, 1922). Of especial relevance to the management of short-onset climate impacts is food preservation, defined as the preparation of familiar foods in ways that make them edible for sometimes months after fresh food resources run out. Among the most widespread practices of this kind are the drying, salting and smoking of fish but also the fermentation of common foods, typically root crops with coconut cream (Aalbersberg et al., 1988; Atchley, 1985; Cox, 1980; Kent, 1987; Navarro et al., 2007; Pollock, 1984); an account of the preparation of long-lasting baked cassava dough (*nogoytam* and *nelet*) from Vanuatu emphasizes its role in post-disaster situations (Iati, 2011).

Certain Pacific Island foods are not customarily eaten (or desired to be eaten) but in the aftermath of disaster will often help sustain affected people; breadfruit is a common example. Others include the *yaka* (*Pueraria lobata*), the Fijian *dawa* (longan) and Ni-Vanuatu *nepatum* and *vovohe* (*Ficus wassa*); a species of fig, *vovohe* is described as the "wisest tree" in northern Pentecost Island because it bears its fruits close to its roots, preventing them from being destroyed in strong winds (Rarai et al., 2022). During famine, people also ate ferns, fungi and leaves not consumed at other times (Clarke & Thaman, 1993; Rarai et al., 2022). Knowledge and use of such "cyclone foods" have generally declined (Handmer & Iveson, 2017, p. 63) but remain known in more traditional contexts, often as part of traditional agroforestry systems which are resilient to cyclone impact (Aalbersberg & Parkinson, 1994; McGuigan et al., 2022). Similarly, the production of food surpluses was once routine in Pacific Island subsistence societies "in which the producing and consuming units were one and the same with some surplus set aside for times of scarcity (seasonal or through extreme events) or used for a variety of forms of exchange" (Campbell, 2015, p. 1316); good examples are the *aragogona* and *maliudu* food gardens of northern Pentecost Island in Vanuatu that have long been used to plant foods which are harvested only to cope with food shortages after extreme events (Rarai et al., 2022).

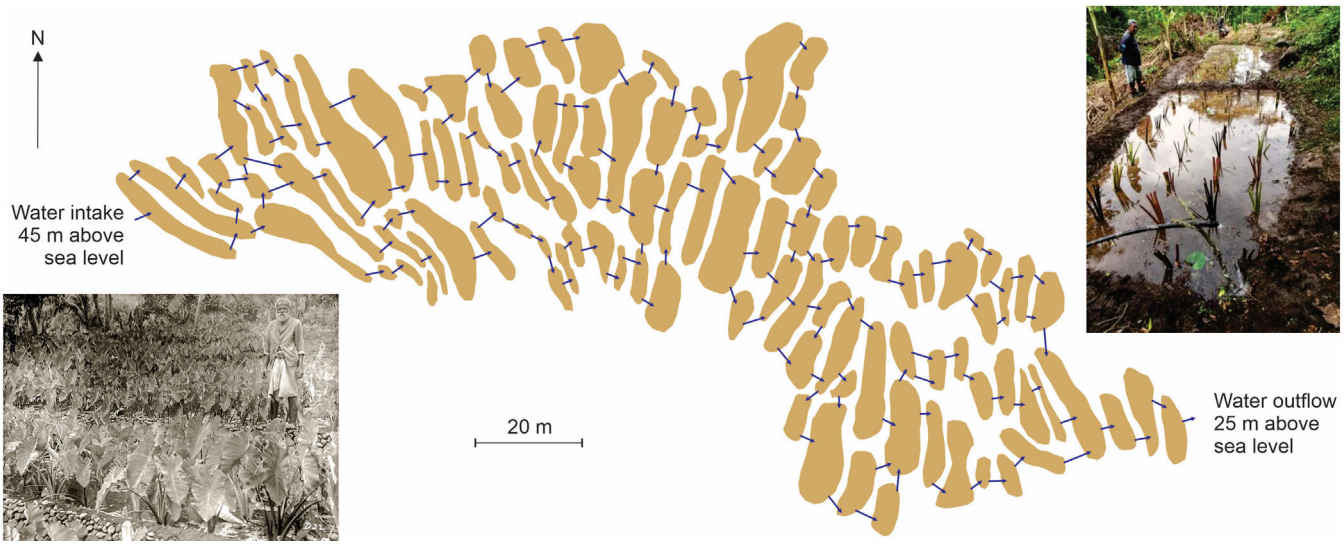

FIGURE 4 Main picture is a map (redrawn from Kuhlken, 1994) showing the taro terrace system named Nadagota at Ravitaki, Kadavu, Fiji in 1992. The system contained 112 separate pondfields with an average size of 51 m^2. Inset bottom left shows taro terraces on Ovalau, Fiji, around the year 1910 (Arthur Hocart). Inset top right shows recently planted pondfield in Navosa, Viti Levu, Fiji [Trevor King].

Accessing adequate clean freshwater in the aftermath of an extreme event (or disaster) is often a major challenge, one for which Pacific Island peoples once deployed a range of coping strategies (Johnson et al., 2021). Of these, many informants reported water divination. Similar challenges are posed by rising sea levels which threaten water security in coastal settings to which some communities have responded by revisiting their traditional practices. On Oneisomw Island (Federated States of Micronesia), for instance, communities have reopened and cleaned their traditional wells, often some distance inland from the coast, and are taking similar measures to those their ancestors took to maintain water quality and supply (Mcleod et al., 2019). In the past in times of water stress, Pacific Island peoples accessed freshwater from caves, coastal freshwater seeps, and from areas of coastal upwelling offshore; most such knowledge and practice appears to have been lost today (Attias et al., 2021; Brosnan et al., 2019; Nunn, 2009).

5.2.2 | Traditional ecological knowledge (TEK) for climate change

Over thousands of years on (relatively) isolated islands, Pacific peoples acquired compendious knowledge about island ecosystems, both marine and terrestrial, and the ways they are best managed to sustain productivity (Kitolelei et al., 2021; Lebel, 2013; Pollard et al., 2015). Such traditional ecological knowledge (TEK) is currently the main focus of efforts in the Pacific Islands to revive TK in order to sustain future livelihoods in a changing climate (Aswani et al., 2020; Matera, 2020; McMillen et al., 2017). Pacific peoples have long depended on island ecosystems to provide healthy diets, something that is dissipating in many island contexts with the inclusion of more imported (often nutrient-poor) foods in daily diets (Hughes & Lawrence, 2005; Sievert et al., 2019). The tendency of post-disaster food aid to comprise solely such foods has an impact on Pacific people's normalization of them in everyday diets.

Much TEK in the Pacific Islands focuses on terrestrial biodiversity, both the conservation of key native/endemic species, especially to counter the impacts of introduced ones, and the maintenance/restoration of biodiverse native ecosystems that are more useful to subsistence-oriented communities than most altered ones (Brodie et al., 2013; Keppel et al., 2006; Park, 1994; Sardos et al., 2016). Given that most Pacific Island residents live close to the ocean and depend routinely on marine foods, considerable TK exists relating to sustainable management of marine ecosystems, especially the nearshore ones that are most heavily utilized (Fache & Pauwels, 2020; Foale et al., 2011; Ram-Bidesi, 2015; Ross et al., 2019). The latter include mangrove ecosystems that were often governed by strict protocols intended to sustain productivity, solutions now lost in many contexts (Argyriou et al., 2018; Pearson et al., 2019, 2020; Veitayaki et al., 2017). Much recent emphasis has been on marine-protected areas (MPAs) that are not only a common contemporary solution for sustaining key marine ecosystems but also have ancient precedents in the Pacific Islands region, making them more acceptable to local communities (Friedlander & Gaymer, 2021; Halpern et al., 2013; Johannes, 1978; Robertson et al., 2020; Veitayaki et al., 2003).

5.2.3 | TK for climate-impacted environmental conservation

For most of their pre-globalization history, Pacific Island societies evolved management strategies like Marine Protected Areas (MPAs) to try and ensure environments, both marine and terrestrial, continued to supply the goods and services on which their human users depended (D'Arcy, 2013; Michalena et al., 2020). It is clear that at such times, Pacific Islanders did not separate land and ocean in the way that is common today, instead evolving management practices like the Hawaiian *ahupua'a*, the Tongan and eastern Fijian (Lauan) *magimagi*, and the New Georgia (Solomon Islands) *pepeso* that were holistic and similar to modern "ridge to reef" management initiatives (Aswani, 2014; Fache & Pauwels, 2022; Mueller-Dombois, 2007; Yeo et al., 2021).

Island peoples also developed tools to guide their interactions with key ecosystems and environments in order to sustain their productivity. To this end, lunar-based seasonal calendars that directed Pacific peoples when to plant and harvest particular foods were conceptualized and communicated orally; only recently have some of these been transcribed (Chambers et al., 2021; Mondragón, 2004). Other tools were commonly deployed following an extreme event that impacted the supply of key goods and services; such tools include communal work, preserved today in practices like the Fijian *solesolevaki*, and the periodic use of taboos on accessing particular places and/or utilizing their resources in order to allow the supply of these to recover (Movono & Becken, 2018; Robertson et al., 2020). Recent research shows that urban–rural migration driven by COVID-19 in the Pacific Islands has led to an improved understanding and use of TK for environmental management among many Pacific Island peoples (Iese, Wairiu, et al., 2021; Movono et al., 2022).

5.2.4 | TK for climate-resistant settlement and house construction

Before Pacific island societies started to become part of a globalized world, typically in the early to mid 19th century, most communities were located inland from the coastline (Nunn, 2007; Nunn & Campbell, 2020). Traditional knowledge guided where to build settlements to minimize their exposure to risk and climate change/variability and was supplemented by knowledge of how to organize settlements so that they would be less exposed to strong winds and waves in particular. With the arrival of foreign missionaries and colonial officials, such knowledge dissipated and many island communities were involuntarily relocated to the coastal fringe, places they often understood to be more exposed to environmental risk (Nunn, Lancini, & Compatangelo-Soussignan, 2022; Siméoni & Ballu, 2012).

House construction in the pre-globalization Pacific Islands was also adapted to local threats, particularly from extreme waves and tropical cyclones. Traditions of building houses on stone platforms may have their origin in "reducing the effects of floods and storm surges" (Campbell, 2006, p. 25); a study of Yapese (Federated States of Micronesia) meeting houses (*faluw*) found that many built in coastal locations have had their underlying stone platforms raised incrementally to accommodate sea-level rise (Figure 5: Nunn et al., 2017).

Traditional houses that can withstand the impacts of hurricane-force winds in the Pacific have particular roof configurations, structural connections (like coconut-fiber rope) that are stretchable, and walls through which air can pass relatively unhindered; Samoan *fale* have no walls although mats can be lowered/raised as desired. As Austin commented of traditional Pacific Islands architecture, it was

> open to the sky rather than closed rooms, of sticks and grass as against mud and stones, poles as against walls, of single cell pavilions rather than labyrinthine complexes, of buildings raised in the air on stilts rather than sunk in the ground, of temporariness as against permanence, tension and weaving rather than compression and building (2001, p. 17).

In Vanuatu in the aftermath of Tropical Cyclone Pam (March 2015), it was found that the unexpectedly low death toll was explainable by adequate time to prepare and, particularly in more rural locations, the use of traditional indicators of an approaching cyclone and of "traditional cyclone houses" (Handmer & Iveson, 2017, p. 63). Cyclone houses

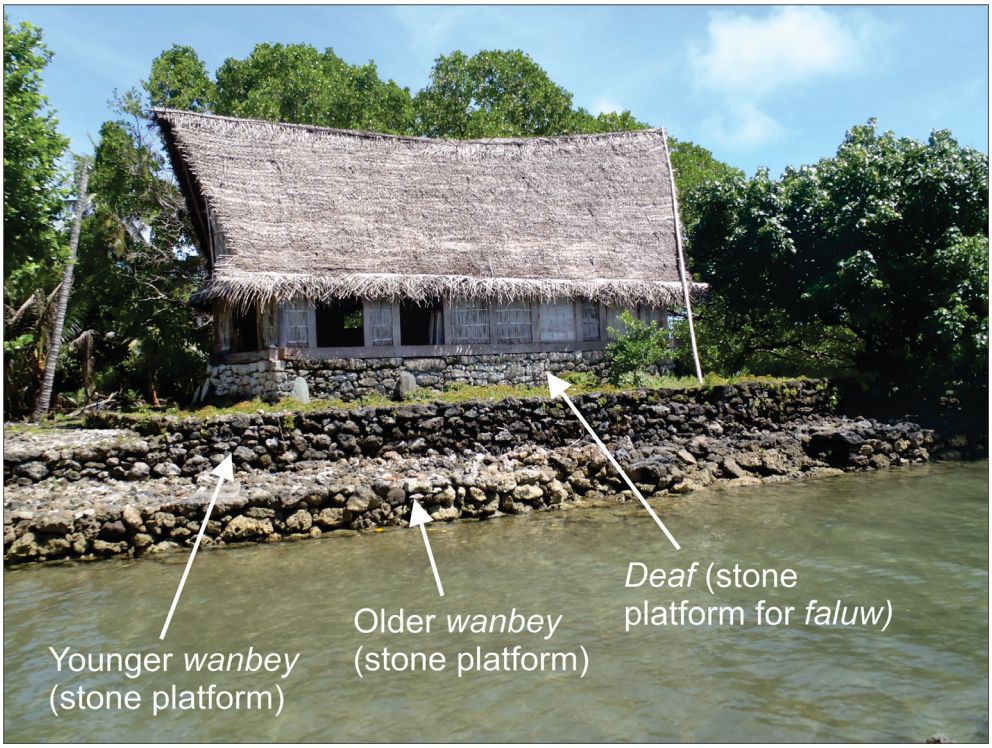

FIGURE 5 The *faluw* (men's house) at Waalooy, Maap, Yap, showing how an extra stone platform (the younger *wanbey*) was added to accommodate rising sea level, a TK-based adaptation to climate change.

include the *gamali* found in every village of northern Pentecost that have displaced caves as preferred community shelters during tropical cyclones. These houses (one is shown in the Graphical Abstract) have

> ... thicker thatch (than normal traditional houses) and a roof that extends to ground level. At least one end of the house is rounded to reduce wind resistance, the door is kept as small as possible and the frames are buried in the ground. The building materials are lashed together (rather than nailed) allowing the buildings to flex and bend without breaking up (Handmer & Iveson, 2017, p. 64).

Similar insights have been reached in other studies from the Pacific Islands (Campbell, 2006; Fujieda & Kobayashi, 2013; Nemani, 2011; Nunn & Campbell, 2020). Sometimes when a cyclone was approaching, people in Samoa would place a layer of heavy coconut fronds on their house roof to help secure it against high winds and reduce the chance of leakage (Turner, 1884) while in the same situation Tongans might remove the entire roof from their dwellings and place it on the ground to reduce the chance of it being broken up (Hurrell, 1984).

6 | DISCUSSION

While there has been an upsurge in discussions of TK in the Pacific Islands region over the past 5–10 years, many of these discussions appear to have been almost-meaningless "statements of intent," possibly intended to placate those from the region who feel that their people's understandings of the worlds they inhabit have been unjustly sidelined in plans to manage a climate-constrained future for the region. There appears little genuine will on the part of many outsiders (or indeed many Pacific Island decision-makers) to document and disseminate TK that may be useful for coping with the multifarious effects of future climate variability and climate change. Given that this situation is running alongside one in which Pacific TK is being rapidly lost, the opportunities for documenting, disseminating and benefiting from this are dwindling (Kitolelei et al., 2021; McMillen et al., 2017; McNamara et al., 2021).

This section discusses two themes of critical importance; first is the importance of conserving the TK of all Pacific peoples and ensuring its value to future climate-change adaptation is understood by everyone involved (Section 6.1); second is how best to integrate TK and global knowledge for the co-production of effective and sustainable pathways for coping with future climate change, especially in rural subsistence-oriented contexts in the Pacific Islands (Section 6.2).

6.1 | Conserving and valuing Pacific TK

The TK that has successfully sustained people living on Pacific islands for thousands of years is endangered, both because it has been supplanted and often devalued by global/western knowledge but also because it is no longer being communicated as effectively from one generation to the next as was once the case (Aswani et al., 2020; McCarter & Gavin, 2014; Shah & Bhat, 2019). In order for TK to become the foundation of future coping with climate change in the Pacific Islands, as we argue, it needs to be actively conserved, effectively disseminated, and re-valued by both Pacific peoples and those from elsewhere concerned with sustainable futures for the region.

A key issue is that traditional knowledge-holders in many Pacific communities are elderly and often die without passing on their TK to the younger generation, a process fundamental to the long-term utility of TK. So the documentation of useful TK (Tiers 1 and 2 in Figure 3) should become a priority in many Pacific Island countries, focused on engaging with those persons with the broadest and most authentic knowledge; for example, in Tonga where the Tonga Meteorological Service has been working to collect weather-linked TK, most informants targeted are over 60 years old. Our study also identifies a conspicuous lack of detailed community-based case studies of TK as a weakness of the current state of knowledge; exceptions exist but many TK surveys often target the most iconic types of knowledge rather than the everyday strategies for survival.

For TK to take its place at the center of future strategies for coping with climate change, its value needs to be acknowledged by everyone involved, both local residents and people from outside the Pacific region who are mandated to help it achieve sustainable futures. For many Pacific peoples, this requires a re-valuing of Pacific TK, an understanding that its great strength is that it evolved to enable the survival of people on particular islands and that it has advantages that cannot be matched by global/western knowledge. Recently there have been calls for climate-change

adaptation in the Pacific region to no longer be donor-led but to be donor-enabled, designed and driven by Pacific peoples, specifically in rural contexts by community leaders who not only hold the greatest stock of place-based TK but are also invested in community futures in ways that outsiders can never be. This requires "that implementers and donors should become facilitators of the desired adaptation aspirations for communities, rather than 'doing' adaptation 'to communities'" (McNamara et al., 2020, p. 638). In this way, TK will become foregrounded in community-based adaptation strategies and make these more likely to succeed.

6.2 | Integrating TK and global knowledge systems

Most Pacific TK not only evolved in (pre-globalization) socio-cultural-ethno-gendered contexts that are quite different to those of today in the Pacific Islands region but it also evolved to cope with climates (and climate changes) that were also distinct from those of today and likely/projected futures. For these reasons it is not possible to uncritically use TK alone (in the Pacific or elsewhere) for addressing future climate-linked challenges, meaning that there is a need to complement TK with western/global science to devise optimal adaptation pathways for particular peoples in particular places (Vierros & Ota, 2019). There are parallels with knowledge integration elsewhere in the world, including the imbricated/braided approach used in North America (Gauvreau & McLaren, 2016; Wilcox et al., 2023).

That said, it is clear that Pacific TK has considerable utility and potential for helping Pacific peoples cope with the varied effects of future climate change. Specifically, we argue, this is because TK evolved as *place-based* knowledge, so is optimal for managing change in a particular place. This explains why it is still often trusted more by the residents of this place than downscaled *generic* (not place-based) solutions derived from western/global scientific knowledge; numerous studies from the Pacific Islands support this position (e.g., de Scally & Doberstein, 2022; Matera, 2020; Nakamura & Kanemasu, 2020; Rantes et al., 2022; Wongbusarakum et al., 2021).

With this in mind, we recommend that future adaptation interventions and policy development involving Pacific peoples, especially those living in rural subsistence-oriented contexts, should be co-produced with local residents in ways that empower them to design and drive these interventions. This requires effective engagement with local (community) residents, requiring outsiders to reframe narratives of "negativity, problems, and weakness" (McNamara et al., 2022, p. 1) to foreground culturally-grounded stakeholder resilience. At the core of effective and sustainable adaptation to future climate change is the development of adaptation pathways, underpinned by *consolidated* TK, that are informed by downscaled climate projections and their likely impacts on local environments, especially their geography and their productivity.

7 | CONCLUSIONS

This research shows that climate resilience is not something that was ever lacking in Pacific Island societies. Pacific Island peoples endured for thousands of years on islands far from continental shores by design not luck. Foundational to this resilience was TK that allowed Pacific peoples to apprehend and withstand the effects of extreme events, short- and longer-onset climate changes (including climate variability). For the future, it is essential to consistently document relevant TK and to integrate this with global/western science to produce effective and sustainable pathways for climate-change adaptation in the Pacific Islands.

A key point is that TK evolved in Pacific Island societies without any need for money. Pacific TK became central to adaptation through people's shared understandings and communal efforts, the latter involving practices that remain important to the sustainability of many rural communities today. Yet the degree to which money has come to be seen today as a necessary preliminary to any type of adaptation is concerning, not least because it has created dependency at both community and national/regional levels in the region. Recent research has called for donors to acknowledge the unsustainability of growing the dependency of Pacific Island countries and the need for this to be replaced by increasing autonomy in which TK would play a central role not least because it is readily adopted by people in cash-limited contexts (Korovulavula et al., 2020; Nunn & Kumar, 2019).

Most authorities agree that climate-change adaptation in the Pacific Islands region is best served by strategies that involve knowledge co-production to which TK and western science both contribute (Matera, 2020; Pilbeam et al., 2019; Plotz et al., 2017). While the precise nature of these strategies will vary, the great strength of TK is that it is place-based

while that of western climate science is its ability to provide robust and downscalable projections of future climate. Together they provide the best chance for sustainable futures across the Pacific Islands region.

AUTHOR CONTRIBUTIONS

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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