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The Palolo Worm as a Cornerstone of Pacific Ecological Time-Reckoning

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Abstract Indigenous knowledge systems that uniquely encode environmental knowledge are vanishing globally in tandem with environmental changes and globalization. In this paper we explore knowledge and uses of the palolo polychaete worms (*Palola* spp.) in time-reckoning, as documented in the anthropological literature on Polynesia and Melanesia. We then introduce preliminary findings from three contemporary cultures, the Raga-, Vureas-, and Netwar-speaking peoples of Vanuatu. Use of the palolo worm as an element in traditional time-reckoning is well-attested in both historical and contemporary literature, and our original research reinforces the notion that it is still a crucial part of ni-Vanuatu ecological calendars. Within the cultures discussed, the annual appearance of the palolo worm is an important temporal event within very complex systems that incorporate plants, animals, agriculture, celestial bodies, the ocean, and human health for the purposes of organizing human activities. These systems, and the place of the palolo worm within them, must be given proper attention in ongoing efforts towards environmental conservation and the documentation and revitalization of traditional knowledge.

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Introduction

Indigenous peoples across the world make use of natural phenomena for the purpose of time-reckoning. Observations of the local environment, ranging from the movements of celestial bodies to phenological cycles of plants and animals, are used to anchor oneself in time and organize schedules of agriculture, hunting, and social events (Harrison 2007). These traditional time-reckoning systems, often called "ecological calendars," encode and display the deep environmental knowledge of their users (Kassam et al. 2018). However, these systems face erosion due to language loss, the adoption of foreign time-reckoning systems (Harrison 2007; Schieffelin 2002), and, in the Pacific, a variety of threats to marine ecosystems.

As stated by Hviding (1996:2), "[l]agoons, reefs, and the near ocean are cornerstones of the environments from which Pacific Islanders derive their material and spiritual sustenance." Marine ecosystems and the traditional knowledge which local people hold concerning them are of both local and global importance, particularly as ocean and reef habitats decline in health across the world (Aswani and Albert 2015). However, even in societies that rely heavily on their marine surroundings, these habitats are but one part of what Cajete (2000:178) calls a "sea of relationships," an Indigenous worldview in which each individual element of nature, including humans, interacts with and influences all the others. Oberndorfer et al. (2017:458) explores this idea in the context of ethnobotany and marine ethnobiology among the Makkovimiut (Inuit Community of Makkovik in Nunatsiavut), noting that "Makkovimiut understand through practice and shared oral traditions how plants support fishing at all stages of the practice

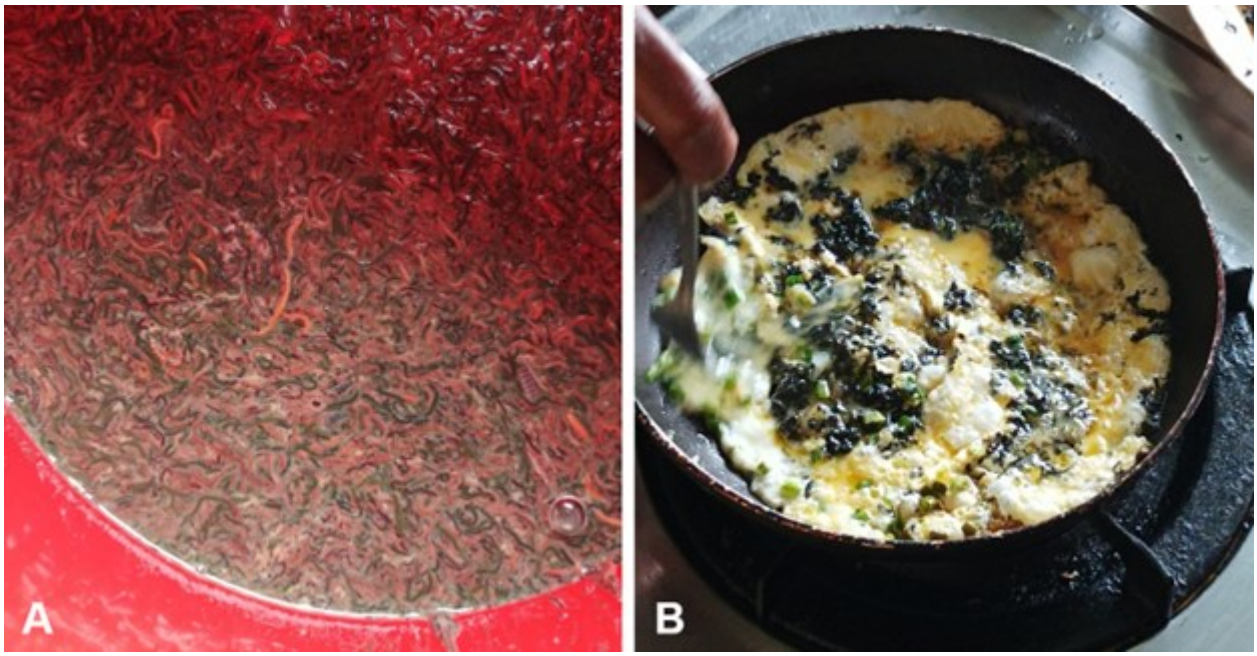

Figure 1 A Male (orange) and female (green) palolo epitokes harvested near Lowanatom, Tanna, Vanuatu. These organs are what ni-Vanuatu and other Pacific peoples most often refer to as worms, rather than the entire animal. **B** Frying palolo worms with egg in Lowanatom. Photos by Dominik M. Ramík.

and how fishing also supports plants". The "sea of relationships" amongst Pacific peoples, the marine environment, and the rest of their local ecosystems is clear when investigating traditional ecological time-reckoning practices.

In Polynesia and Melanesia, ecological calendars exhibit remarkable diversity and complexity, reflecting the wide array of environmental rhythms and events that island peoples in this region regularly experience. These systems include—but invariably go beyond—Western notions of lunar and solar calendrics, incorporating cycles of the sun and moon, the movements of stars, patterns of clouds and weather, changes in the ocean and tides, and the phenological cycles of numerous plants and animals. The various cultures of Vanuatu have rich systems of time-reckoning which make use of a wide array of "calendar plants" to determine the timing of agricultural activities, schedule the harvest of marine resources, and inform health decisions (Balick and Plunkett 2018). Often, ni-Vanuatu time-reckoning also includes nature-based rituals by which specialists reportedly influence the weather, sun, or waves. A widespread component in time-reckoning systems of Vanuatu and the broader Oceanic region is not a plant, but an animal: the marine polychaete worm known widely by its Samoan name, "palolo" (genus *Palola*), which has one of the most regular natural cycles in Pacific ecosystems.

Palolo are polychaete worms that grow to over a third of a meter in length and inhabit reefs around many Pacific islands. Rarely exiting the holes and crevices in which they hide, they stay put until the last quarter of the moons of October and November (and sometimes December), when every palolo worm in Polynesia and eastern Melanesia splits in half (Schulze and Timm 2012). The anterior end of each worm, with its head and other major organs, remains in its reef hideout, while the *epitoke* or posterior end, with reproductive organs, swims upward in the water column to the sea surface (Figure 1). The *epitoke* swims "almost as if it were a separate animal in its own right. Indeed, it has even developed a pair of eyes to assist it in locating the surface" (Shuker 2001:94)[1].

Massive swarms of these *epitokes* are both well-known and highly predictable in their appearance. Although the most famous "palolo worm" is *Palola viridis*, first described from Samoa (Stair 1847), polychaete swarms in the South Pacific can contain multiple *Palola* species and even worms from other families (such as Nereididae; see Fowler 2017; Schulze and Timm 2012). Furthermore, the taxonomy of the genus *Palola* is not fully settled, although specimens from Samoa and Vanuatu are likely to be *P. viridis*

(Schulze and Timm 2012). While a variety of polychaete worms are valued by various cultures in Indonesia, including as elements in time-reckoning (Forth 1983; Fowler 2017; Tadataka 2018), and as important foodstuffs, such as nereid worms in Vietnam (Lieu and Nguyen 2021), the current study is only concerned with *Palola* spp. that swarm from Papua New Guinea eastward to Samoa. The remarkable biology of these worms has made its mark on a diverse range of cultures in this region, appearing in traditional foodways, cosmology, and ritual, in addition to time-reckoning.

Here, we briefly summarize several case studies from the literature on Melanesia and Polynesia. We then discuss three cases from Vanuatu: those of the Raga-speaking people of northern Pentecost Island, Vureas language speakers of Vanua Lava, and the Netwar-speaking people of Tanna, which we recently began to document in collaboration with local experts. We demonstrate that the palolo worm is a cornerstone of many different Pacific traditions that play an integral role in Indigenous time-reckoning. This worm is one strand in a complex web of environmental cycles which inform the timing of human activity in these places.

Methods

We employed two methodologies to gather information on cultures that possess palolo knowledge. First, we surveyed approximately 200 works spanning the subfields of travel writing, ethnography, and anthropology, which span 174 years (1847–2021). We coded these sources for any reference to palolo knowledge, as well as their use in ecological calendars and other time-reckoning techniques. While the total number of Polynesian and Melanesian cultures taken together number nearly 2,000, few are well documented, nor is it likely that all have contact with the palolo worm. Our data set includes information from 35 cultures; however, we acknowledge that there may be a great deal more palolo lore distributed across Oceania that remains to be documented.

Second, we interviewed eight culture experts from the Raga-speaking people of northern Pentecost Island, who are known to possess significant palolo lore; five culture experts from the Vureas-speaking villages of Wasaga and Vetimbosa on Vanua Lava; and four experts from the Netwar language area of Tanna. The relationships that sparked this research on the palolo worm were formed while working on the *Plants and People of Vanuatu* project, a collaboration between botanists, ethnobotanists, mycologists, cultural specialists, linguists, and conservationists. This project aims to study and preserve plants, fungi, and associated traditional knowledge in Vanuatu, including traditional ecological calendars.

Our dialogue with the Raga community was conducted in both English and the local Raga (or Hano) language, which has approximately 7,500 speakers (Eberhard et al. 2022). On Vanua Lava, work was conducted in Vureas (or Vurës), which is spoken in the southern part of the island by around 2,000 people (Malau 2021). The Netwar language, spoken by approximately 12,000 people (Eberhard et al. 2022), was used during research in southwestern Tanna.

Our approach is not one of data extraction, but rather co-production of knowledge, based on mutual trust and reciprocity, and the willingness of community experts to share knowledge with us, and through us, to a global audience. The knowledge is shared with the understanding that it remains the intellectual property of the Raga, Vureas, and Netwar language communities and will be fully attributed to them, both individually and collectively.

Results

Pacific cultures have closely observed the palolo worm because of its nutritional value, temporal predictability, and the dramatic scene it creates on the reefs when it spawns. Rev. John Stair's (1847) experience of palolo swarms in Samoa resulted in its formal description, and much has been written about it since. We surveyed the anthropological literature from Polynesia and Melanesia and found the palolo worm to be a common theme, with many references to its role in time-reckoning.

Literature Survey

In Vanuatu, mention of the palolo worm's place in time-reckoning stretches back at least to the late nineteenth century. Codrington (1891:350) notes how, on Mota Island in the northern Banks group, "the strange and exciting appearance of the well-known annelid, the palolo, *un*, sets a wide mark on the seasons." The people of Mota attribute the natural cycles of their local environment to a spirit known as *Qat*, and by careful observation of these rhythms are able to both predict other natural phenomena and organize their agricultural schedule. The cool season on Mota is marked by the appearance of *rara* (genus *Erythrina*) flowers, and that same flower's fall is the

Figure 2 *Erythrina fusca*, one of two species of *Erythrina* (rara in the Mota and Raga languages), native to Vanuatu. This species has (**A, B**) orange to (**C**) bright red flowers. When these flowers fall, it is a signal to people on Mota and Pentecost that palolo (*un* in Mota, *udu* in Raga) will soon appear. [Photo credits: A & B, Laurence Ramon (LR-128); C, Kate Armstrong (KEA-588).]

signal that the palolo worm will soon surface (Figure 2)[2]. Following the fading of the *rara*, three months are named after the worm, and each palolo swarm signals the current developmental stage of the yam (*Dioscorea* spp.) crop. October is known as *Un Rig* ("little palolo") or *Un Gogona* ("bitter palolo") because worms first appear at this time, and this signals that yams are nearing maturity. November is *Un Lava* ("great palolo"), when large swarms of worms surface and everyone goes down to the beach to collect them. At this time, all yams are harvested. Finally, December is *Werei* ("rump [of the palolo]") when the last few worms can be found, *ganoi*, the west wind blows in, and the gardens must be cleared. The rest of the Mota calendar is based off other environmental indicators, including reeds, *rara*, and winds (Codrington 1891).

On Loh, in the Torres Islands of northern Vanuatu, the palolo worm is part of a ritual that realigns the sun and keeps the seasons on track. Like other ni-Vanuatu, the people of Loh are horticulturalists and therefore have a complex system of organizing time as it relates to the propagation and harvesting of crop plants. The markers of this time-reckoning system include broad seasonal changes, celestial bodies including the sun and moon, the progression of the tides, and also animals (Mondragón 2004). Components of this system, such as the *tuwiä* bird (*Tringa incana*) and the sun, are said to have *mena*, which refers to the supernatural abilities of powerful people, animals, and objects to "evoke various kinds of transformative forces that lie inherent in the living world" (Mondragón 2004:291).

The *tuwiä* bird heralds the arrival of the palolo, known locally as *nút*, in the Lo-Toga language spoken on Loh. When a strong stench from the sea confirms the worm's arrival, the islanders descend to the rocky shore for harvest. But before the worms can be eaten, the people must ensure that the sun will make its way back north after the summer solstice. In the ritual of the "sun-Ureparapara alignment," islanders perform a magical chant while transferring the harvested *nút* from worm-catching nets to the pandanus baskets in which they are carried to the cook site. This chant both "turns" the palolo worm into food and "turns" the sun towards the north, aligning it over the island of Ureparapara to the southeast. Failing to perform this ritual would be catastrophic: the sun would not be imbued with *mena* and would thus not begin to shift in the sky following the solstice, leading to crop failure. The palolo worm and the *tuwiä* bird, together with the people themselves and their traditional songs and

rituals, act as integral parts in the web of magic, heavenly bodies, and living things that synchronize life for these islanders (Mondragón 2004).

Samoans also possess a remarkable system of time-reckoning and weather prediction based on careful and precise observations of the environment. Stair's (1847:18) first description of the cultural importance of palolo worms in Samoa suggests a detailed system for predicting their arrival:

> The natives are exceedingly fond of them, and calculate with great exactness the time of their appearance, which is looked forward to with great interest. The worms are caught in small baskets, beautifully made, and when taken on shore are tied up in leaves in small bundles, and baked. Great quantities are eaten undressed, but either dressed or undressed are esteemed a great delicacy. Such is the desire to eat Palolo by all classes, that immediately [after] the fishing parties reach the shore, messengers are despatched in all directions with large quantities to parts of the island on which none appear.

Today, the adopted Gregorian calendar is often used to determine whether October or November will see the strongest palolo rising, but traditional environmental cues are also still consulted. Smetzer (1969:68) recorded the following account from an unnamed Samoan chief,

> If you want to know when the palolo is coming, the first thing you have to do is watch for the signs in nature. Because the people in the old days did not have any calendar and they had to look around at the trees and the shrubs and the moon and things like that to tell what is the time of the year.

A few of these signals include "the flowering of the *moso'oi* tree [*Cananga odorata*], the closing of the *palulu* flower [any of several species of the Convolvulaceae], a strong smell from the reef, brown foamy scum on the ocean, and abrupt weather changes or bad weather" (Itano 2009). Other accounts reference bending breadfruit branches (Smetzer 1969), the appearance of a small fish known as *o le mosimosi-palolo*, an abundance of cuttlefish, long nights, and the same discoloration of the tide as signals for the palolo's coming (Stair 1897), as well as prediction of the worm's arrival based on the sun, moon, and stars (Burrows 1955).

The Samoan calendar is divided into two seasons: the wetter *Vai To'elau* (February to July) and the drier *Vai Palolo* (July to January). The first two months of *Vai Palolo* are also named after the palolo worm: *Palolo Mua* or 'the first palolo' and *Palolo Muli* or 'the last palolo.' Interestingly, the palolo worm never surfaces during these months, but since the actual arrival of the palolo is strongly anticipated and accurately predicted by Samoans each year in October or November, the naming of these months is somewhat of an enigma (Lefale 2010; Samoan Society 1928; Stair 1897). One explanation is given by Tofa I'iga Pisa, who says that the last of the previous year's preserved palolo was served at this time, "in anticipation of the next rising" (Smetzer 1969:70).

The calendar of the Polynesian island of Futuna (part of Wallis and Futuna, just to the west of Samoa) has months with identical names but corresponding to the correct times when the palolo worm swarms. *Palolo Mua* roughly corresponds to October, while November is *Palolo Muli*. Intriguingly, the palolo worm does not appear in Futuna today. Perhaps it once did, or perhaps these calendars are evidence of an ancestral Polynesian calendar that has since been adapted to various islands in the Polynesian sphere (Kirch 1994).

The palolo worm is also present in nearby Fiji, which, at the eastern edge of Melanesia, has many Polynesian cultural influences. Two Fijian months named after the palolo align with the times when it surfaces. The worm first rises in the month of *Vula i Balolo Lalai*, which is marked by the flowering of several different plants, and the second, often larger rising occurs during the month of *Vula i Balolo Levu*, when several fruits are ready to be harvested (Gatty 2009). However, while the worm does appear during these months, it does not appear everywhere. Due to palolo's cultural significance, Fijian villages with no worm have designated "substitute *balolo*," all of which are also edible sea creatures that can only be harvested during a short period each year. On Lakeba Island, a wide range of animals are called *balolo*. The village of Tubou has the true palolo, while people in Nukunuku refer to *nuqa*, the rabbit fish (*Siganus vermiculatus*), as their *balolo*. Waciwaci villagers harvest the red land crab *lairo* (*Cardisoma* sp.) in November and December and have a second *balolo* as well: the *salala*, or long-jawed mackerel (*Rastrelliger kanagurta*). Vakano also has two *balolo*: the unicorn fish *ta* (*Nasus* spp.) and *saku*, a type of billfish (Gatty 2009).

The residents of Vakuta, one of the Trobriand Islands in Papua New Guinea, harvest as many palolo worms as possible during the full moon of October-November (Austen 1945). The worms rise during the night and begin to disperse at the false dawn (4 a.m.), almost completely disappearing by daytime. As the worms move away, the Vakutans return to their village and hold the *yoba* ceremony, "which consists of religious rites associated with the return of the *baloma*, or spirits of the dead, from the underworld land of Tuma" (Austen 1945:28). To the Vakutans, the palolo worm is known as *milamala*, however on Kiriwina, the main island of the Trobriands, *milamala* refers to a full moon in August-September. As it turns out, the palolo worm does not occur at all on the island of Kiriwina, but the full moon named for it is still very important to the islanders. They hold their *yoba* ceremony on this *milamala* moon, which marks the new year, though occasionally, they find that the moons "go silly" and don't seem to be occurring at the right time in the solar year (Austen 1939, 1945). The palolo worm occurs during the same phase of the October and November moons, meaning that its phenological cycle is aligned with the solar year, rather than a set number of lunar cycles. This pattern allows the palolo worm's rising to serve as an event which people on Vakuta, and elsewhere in the Pacific, use to recalibrate their calendars. Kiriwina, however, only has twelve *kweluva*, or garden (lunar) periods, and no worm to mark its *milamala*; furthermore, its calendar tends to fall out of synch. To adjust the *kweluva* to the solar year, those living on Kiriwina look to the astronomers of Wawela village, who use their deep knowledge of the movements of stars and constellations to determine when different events in the agricultural cycle should occur. Even using this system, Trobrianders still complain of over- and underabundance of yam harvests due the years when the moon "goes silly" (Austen 1939; Leach 1950).

Similarly, Wogeo language speakers from the Schouten Islands in western PNG experience problems wherein their agricultural schedule is thrown off by agricultural fluctuation and the mismatch between the lunar and solar year (Leach 1950). They allocate roughly three months each year to the appearance of the fruits of the "almond" (presumably *Terminalia catappa*) and *wasek* (*T. kaernbachii*). When this period is complete, they count four lunar months to predict the appearance of the palolo worm. However, people occasionally set out to harvest the palolo a month too soon. This is most likely due to fluctuations in the length of *Terminalia* fruiting and suggests that the Wogeo calendrical system is not entirely predictive (at least in terms of the timing of palolo swarms). Instead, there appear to be two anchors each year to realign the lunar calendar to the solar. One of these is the palolo worm's appearance in October and November. Rather than predicting when the worm swarms, Wogeo speakers count the number of months from its appearance. The second anchor is the placement of the Pleiades star cluster in the night sky. If the Pleiades do not appear precisely when they are expected, an additional month is intercalated into the calendar to recalibrate. By using both of these checks, the people of the Schouten Islands are able to successfully orient the schedule of their various rituals and economic activities (Leach 1950).

Codrington's (1891) work in southern Malaita, Solomon Islands, suggests another interesting case in which the rising of the palolo worm is predicted using a sidereal (star) calendar. To speakers of the Sa'a language, the palolo worm appears in the conception of two constellations, "At Saa the Southern Cross is *ape*, the net, with four men letting it down to catch the palolo, and the Pointers are two men cooking what has been caught, because the palolo appears when one of the Pointers appears above the horizon" (Codrington 1891:349). The latter point reveals that people in southern Malaita, as in other parts of Melanesia, carefully predict the timing of the appearance of the palolo by watching the movements of the stars. This excerpt suggests further that the palolo worm is important at the very least in a culinary sense.

Original Research from Vanuatu

Speakers of the Raga language in the northern part of Pentecost Island, Vanuatu were interviewed in 2020; speakers of the Vureas language of Vanua Lava were interviewed in 2021 and 2022; and Netwar speakers from Tanna were interviewed in 2022. All three peoples reported use of the palolo worm in their time-reckoning systems and cultural lore.

On Pentecost, local experts relayed a story about a man who was murdered long ago. He was buried in an enclosed space, but his blood flowed down into the sea and turned into palolo worms (known locally as *udu*). His buried body became one of the island's staple crops, the *damu* or yam. Today, the worms still have a strong relationship with the islanders' crops.

Like the people of Mota, Raga speakers call *Erythrina* flowers *rara* and use their fall as a signal that the palolo worms will soon surface (Figure 2). In Raga, *Uda Rara*, the month that corresponds to September, translates to "palolo worm, *Erythrina* flower", clearly conveying this relationship. During *Udu Malalageha* ("palolo worm, new life") and *Udu Matala* ("palolo worm goes away"), the following two months, a heavy rain called *meren udu* (or *pispis blong udu* "piss of palolo" in Bislama) is another sign that the palolo rising is nearing. After the full moon in each of these months, people count the days. On the night of the fifth day, an abundance of snakes and crabs crossing the road serves as a last signal that the worm's rising is imminent.

When the worms surface, Raga speakers attract them with a song and light, traditionally coconut-leaf torches but now more frequently electric lights. The worms are scooped up with many different tools and can be eaten raw on the spot. More commonly, the harvested worms are wrapped in leaves and baked in an earth oven, cooked in bamboo, or fried. The palolo worm is a highly valued foodstuff on Pentecost and is traded for red mats and livestock. It is also believed that the stench that arises from the sea at this time makes plants grow better, and the water from the palolo-laden reef is used both as a fertilizer for crops and as bathwater to help children grow. The behavior of the palolo worm and its relationship to the local environment can be clearly seen in the naming and description of the months surrounding the palolo swarms (Table 1).

Netwar language speakers on Tanna Island, in southern Vanuatu, call the palolo worm *mim*, a general term for most worms and caterpillars, or *mim taha tehé,* "*mim* from the sea." People from three villages in coastal Netwar-speaking areas told us that *mim* had not been consumed by their ancestors, calling it *nam napnapen am*, "a useless fish/sea creature." They only learned how to catch and eat them from people of Pentecost and Malakula, notably nuns who arrived in the 1960s and 1970s. Some contrasted them to *prisin* (large larvae of longhorn beetles, including *Olethrius tyrannus*) that are considered to be delicious and a proper food of the ancestors while *mim* was only to feed fish.

While palolo worms were not traditionally consumed on Tanna, their rising is highly anticipated because of its association with fish. During the rising of *mim*, it is said that fishing with bait is useless because the fish are already full. However, as fish concentrate around the palolo worms to feed on them, it is a time when one can catch a lot of fish by throwing a net or by spearing them with a knife in shallow water or tidal pools. Large catches of *tekapelew*, a juvenile fish otherwise known as *melao niés* (a common name for several species of *Sargocentron*, called *red fis* in Bislama) were mentioned in connection with the appearance of palolo. Despite palolo's relatively recent introduction into Netwar cuisine, it is now an established part of the local ecological calendar. Albertine, an elder Netwar speaker from Lowanatom, explains how the worm's rising is predicted and how it is caught:

> Towards the end of the year, people observe the moon phases. When the time of full moon is passed and the moon rises later in the night, there is a smell of raw fish coming from the sea as far as a few hundred meters inland. People will then go fetch *numasia* [dry coconut leaves], fasten them together as a torch [*nesia*]. When the time is really close, there is often a very fine and thin rain [*noroan*] during the day or in the evening. In the evening as the night is dark, people will get their torches and go to the passes in coral reefs. *Mim* will come in its *karem* [the same term used for woven *Pandanus* bag] and go through the pass. They are all together, many different colors and they make a dim light. Sometimes when you expose them to light, they will break from their *karem* and disperse, but when you are lucky, you can grab the entire lot into a mosquito net or cloth. If they break loose, you will need to fetch them all around the reef. You need to hurry because as soon as the moon rises, they will go all around the place and it is hard to catch them. Before, we would only make a *laplap* of them, being ready the day of their arrival and prepare the *laplap* mash in advance. Now we cook them differently, like frying [Figure 1]. Sometimes they will come two nights in a row, but the second time it may only be the last of the first lot arriving the night ago.

Chiefs Hosia Waras and Eli Field Malau of Vetimbosa, Vanua Lava in northern Vanuatu record a Vureas-language ecological calendar that relates plant phenology to the weather, crop cycles, and human health (Caillon and Malau 2002). In our findings,

Table 1 The Raga Calendar.

Month name	Gregorian equivalent	Translation	Details
Bora Tirigi	January	"small birth" (new growth)	Plants start to germinate, there are lots of flies due to many leaves on the ground, food availability is less.
Bora Lavoa	February	"big birth"	Plants get larger and flies multiply, people sense that there are enough resources available.
Vula Barai	March	"moon is not quite full"	Resources available but will soon be gone. Waves are longer, but do not cause destruction. Trees and plants grow well but a small number of leaves fall off the tree.
Langisi	April	—	Time of planting yam.
Mariri	May	"leaves drying"	Yam leaves are drying (but some are still green).
Tarang Tirigi	June	—	Yam leaves fully dry.
Tarang Lavoa	July	—	Yams are ready to be harvested.
Rara Memea	August	"*Erythrina* is red"	*Erythrina* flowers are in full bloom.
Udu Rara	September	"palolo worm, *Erythrina* flower"	*Erythrina* flowers are falling, the worm is still "red and in the womb."
Udu Malalageha	October	"palolo worm, new life"	Worms are caught, wind blows through trees and makes plants grow well, there is heavy rain. Palolo water used as fertilizer and bath water for children.
Udu Matala	November	"palolo worm goes away"	Last palolo swarm, continuing heavy rains. Plants do not grow very well, and you get hungry quickly.
Ulu Gai Tavu	December	—	Waves roll from a long way off and gently crash against the coast. All trees and the plants in the garden grow well and people feel happy about their crops.

Vureas speakers also describe a strong connection between the palolo worm, which they call *hūn* or *un*, and environmental time indicators. When the leaves of the *wehr* tree (*Casuarina equisetifolia* or *oktri* [oak tree] in Bislama [Figure 3]) begin to turn red and a specific seabird appears in the village it is the month *Voromal*, or October. As the time of palolo nears, the sea also turns "dirty" and brown with many dead branches floating on it and gives off a fishy smell. From the first day when the moon is visible in daylight during this month, the people of Vanua Lava begin to count the days. On the night of the sixth day, harvest begins on the long reef along Wasaga Village's shoreline. The villagers light a large fire on a dry section of reef and an expert sings a song (Table 2) to attract the worms to shore. With the worms aggregating by the shore, people use sticks or brooms to harvest them. After that morning, no more worms can be found during *Voromal*, but the same process of counting the daytime moons and harvesting the worms is repeated for the second annual appearance of the palolo during *Selegdem*, or November, for which no ecological indicators were recorded.

Upon return to the village, people rinse the palolo worm with water up to five times. The rinse water is saved and can be used in bath water as a custom medicine for the treatment of many conditions including fever, scabies, red eye (conjunctivitis),

Figure 3 *Casuarina equisetifolia* (*wehr* in Vureas, *oktri* in Bislama) **A** tree, **B** branch with carpellate flowers, and **C** cone-like fruits. The leaves of this species turn reddish as they senesce, signaling to Vureas-speaking people on Vanua Lava that *hūn* (palolo) will soon appear. Photo credits: A, M.J. Balick (*MB-5092*); B, G.M. Plunkett (*GMP-5225*); C, G.M. Plunkett (*GMP-5227B*)[3].

wounds, etc. Strained palolo worms are baked in a ground oven in *laplap* leaf (*Heliconia indica*) and, once removed, served on a bed of *lūt* (called *nalot* in Bislama). *Lūt* is a preparation of a mashed starchy food (such as taro or breadfruit) cooked aboveground and served on large, dedicated wooden plates, in which every family or household takes part in making one plate. Additional flavor can be added by placing nuts such as *nagai* (*Canarium* spp.) on top. Palolo can be preserved this way for up to two weeks.

Discussion

Our original research from Vanuatu—along with the prior accounts taken from the literature—shows that the palolo worm is a cornerstone of Polynesian and Melanesian time-reckoning and cultural identity. While the worm's importance in north and central Vanuatu is documented and known internally to be a nationwide, cross-cultural phenomenon (Mondragón 2004), its place in the culture and time-reckoning of southern Vanuatu has not previously been portrayed to a global audience. Its widespread use across multiple cultures and locations, likely including others which have not yet been documented, reveals how natural cycles can beneficially inform agriculture and other human behaviors. Pacific peoples do not incorporate the worm into a system of abstract calendrics but rather view it as one critical piece of a complex system of ecological time-reckoning involving animals, plants, agricultural cycles, celestial bodies, the ocean, and human health. Ecological calendars are themselves very important in the Pacific, as evidenced by the results of the *Plants and People of Vanuatu* project, which identified more than 100 calendar plants used across multiple islands and language groups.

Like many other aspects of Pacific life, human-palolo interactions are currently under threat from

Table 2 Vureas language palolo song, sung by an expert from Vanua Lava during the palolo harvest, with English translation.

Original (Vureas language)	English translation
Un ē gër me ē qeōrōr e,	Palolo, swim to us, the tide is getting low,
i we un ē we un lam ē, mē siger teñteñ ē.	palolo, swim home to us, you are crying.
Un ē mē gër me, un ē mē gër me,	Palolo, swim to us, palolo swim to us,
kemem gö mörös wor kēmi ē,	we really want you,
kēmi gö mörös wor kemen ē,	you really want us,
un ē mē gër me, un ē mē gër me.	palolo, swim to us, palolo swim to us.

ongoing knowledge erosion and climate change, even as they develop and evolve. During our work in Vanuatu, people have voiced concerns about changes in the predictability and timing of the seasons, as well as dangers posed by Oceanic cyclones. These changes affect the timing of signals in ecological calendars, while climate change and habitat destruction threaten to remove some signals entirely. Climate change alters the phenology of plants, affecting neighboring plants differently (Pérez-Ramos et al. 2020), while rising ocean temperatures and acidification have been proven to negatively affect the phenology of both ocean ecosystems as a whole (Harley et al. 2006) and marine polychaete worms specifically (Freitas et al. 2016).

In these intricate Indigenous ecological calendars, disruption of one element is a threat to the whole system. The disruption or loss of palolo worm swarms would be particularly tragic, as it is utilized so widely not only in time-reckoning but in foodways, medicine, and cultural identity. The ongoing threats to these time-reckoning systems highlight the need to support and collaboratively document traditional knowledge and language. Research shows that these time-reckoning systems can serve as adaptive tools in the face of climate change (Kassam et al. 2011, 2018), but they cannot in fact be extricated from the local language, geography, and biota. Thus, research on these systems must be appropriately accompanied by efforts to protect them.

Notes

[1]These "eyes," or more accurately eye spots, are light sensors, one of which is located on each segment of the palolo *epitoke* (Schulze and Timm 2012).

[2]Raga linguistic, botanical, and cultural data relevant to this research can also be found in the Raga Talking Dictionary (http://talkingdictionary.swarthmore.edu/raga/), a product of the *Plants and People of Vanuatu* project developed to preserve and revitalize the local language and knowledge.

[3]Plant vouchers are deposited at PVNH and NY.

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Declarations

Permissions: This work was carried out under a research license from the Vanuatu Department of Environmental Protection and Conservation, Forestry Department, and Vanuatu Cultural Centre. The Swarthmore College IRB determined that this project does not constitute research with human subjects and does not require IRB approval. Co-author Harrison was affiliated with Swarthmore during the research period

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References Cited

Aswani, S., and S. Albert. 2015. Change in Roviana Lagoon Coral Reef Ethnobiology. In *Ethnobiology of Corals and Coral Reefs*, edited by N. Narchi and L. L. Price, pp. 157–175. Springer, Cham, Switzerland.

Austen, L. 1939. The Seasonal Gardening Calendar of Kiriwina, Trobriand Islands. *Oceania* 9:237—53. DOI:10.1002/j.1834-4461.1939.tb00231.x.

Austen, L. 1945. Cultural Changes in Kiriwina. *Oceania* 16:15–60.

Balick, M. J., and G. M. Plunkett. 2018. Plants mo Pipol blong Vanuatu: Calendar Plants. *Island Life*. Available at: https://www.islandlifemag.com/island-life-magazine/plants-mo-pipol-blong-vanuatu-plants-calendars/. Published on July 6, 2018.

Burrows, W. 1955. "Palolo": Notes on the Periodic Appearance of the Annelid Worm *Eunice viridis* (Gray) in the South-West Pacific Islands. *Journal of the Polynesian Society* 64:137–154.

Caillon, S., and E. F. Malau. 2002. *Coconuts and Taro from the West Coast of Vanua Lava (Vanuatu): An Ethno-agronomic Inventory*. IRD, Orléans, France.

Cajete, G. 2000. *Native Science: Natural Laws of Interdependence*. Clear Light Publishers, Santa Fe.

Codrington, R. H. 1891. *The Melanesians: Studies in Their Anthropology and Folk-Lore*. Clarendon Press, Oxford.

Eberhard, D. M., G. F. Simons, and C. D. Fennig, eds. 2022. *Ethnologue: Languages of the World*, 24th ed. SIL International, Dallas, TX.

Forth, G. 1983. Time and Temporal Classification in Rindi, Eastern Sumba. *Bijdragen to de Taal-, Land- en Volkenkunde* 139:46–80. DOI:10.1163/22134379-90003455.

Fowler, C. T. 2016. *Biosocial Synchrony on Sumba: Multispecies Relationships and Environmental Variations in Indonesia*. Lexington Books, Lanham, MD.

Freitas, R., A. Pires, C. Velez, A. Almeida, A. Moreira, F. J. Wrona, A. M. V. M. Soares, and E. Figueira. 2016. Effects of Seawater Acidification on *Diopatra neapolitana* (Polychaete, Onuphidae): Biochemical and Regenerative Capacity Responses. *Ecological Indicators* 60:152–161. DOI:10.1016/j.ecolind.2015.06.032.

Gatty, R. 2009. *Fijian-English Dictionary: With Notes on Fijian Culture and Natural History*. R. Gatty, Suva, Fiji.

Harrison, K. D. 2007. *When Languages Die: The Extinction of the World's Languages and the Erosion of Human Knowledge*. Oxford University Press, New York.

Harley, C. D. G., A. R. Hughes, K. M. Hultgren, B. G. Miner, C. J. B. Sorte, C. S. Thornber, L. F. Rodriguez, L. Tomanek, and S. L. Williams. 2006. The Impacts of Climate Change in Coastal Marine Systems. *Ecology Letters* 9:228–241. DOI:10.1111/j.1461-0248.2005.00871.x.

Hviding, E. 1996. *Guardians of Marovo Lagoon: Practice, Place, and Politics in Maritime Melanesia*. University of Hawai'i Press, Honolulu, HI.

Itano, D. 2009. Palolo Swarming. In *Natural History Guide to American Samoa*, 3rd edition, edited by P. Craig, pp. 32–33. National Park of American Samoa, Pago Pago, American Samoa.

Kassam, K. A. S., M. L. Ruelle, C. Samimi, A. Trabucco, and J. Xu. 2018. Anticipating Climatic Variability: The Potential of Ecological Calendars. *Human Ecology* 46:249–257. DOI:10.1007/s10745-018-9970-5.

Kassam, K. A. S., U. Bulbulshoev, and M. Ruelle. 2011. Ecology of Time: Calendar of the Human Body in the Pamir Mountains. *Journal of Persianate Studies* 4:146–170. DOI:10.1163/187471611X600369.

Kirch, P. V. 1994. The Pre-Christian Ritual Cycle of Futuna, Western Polynesia. *Journal of the Polynesian Society* 103:255–298.

Leach, E. R. 1950. Primitive Calendars. *Oceania* 20:245–262. DOI:10.1002/j.1834-4461.1950.tb00164.x.

Lefale, P. F. 2010. *Ua 'afa le Aso* Stormy Weather Today: Traditional Ecological Knowledge of Weather and Climate. The Samoa Experience. *Climatic Change* 100:317–335. DOI:10.1007/s10584-009-9722-z.

Lieu, D., and D. Nguyen. 2021. In Photos: Cha Ruoi—Vietnam's Famous Sand Worm Omelet. *Vietnam Life*. Available at: https://vietnamlife.tuoitrenews.vn/news/photo/20211120/in-photos-cha-ruoi-vietnams-famous-and-worm-omelet/64236.html. Accessed on November 20, 2021.

Malau, C. 2021. *A Dictionary of Vurës, Vanuatu*. Australian National University Press, Canberra.

Mondragón, C. 2004. Worms and *Mana*: The Traditional Calendar of the Torres Islands, Vanuatu. *Oceania* 74:289–308. DOI:10.1002/j.1834-4461.2004.tb02856.x.

Oberndorfer, E., N. Winters, C. Gear, G. Ljubicic, and J. Lundholm. 2017. Plants in a "Sea of Relationships": Networks of Plants and Fishing in Makkovik, Nunatsiavut (Labrador, Canada). *Journal of Ethnobiology* 37:458–477. DOI:10.2993/0278-0771-37.3.458.

Pérez-Ramos, I. M., J. Cambrollé, M. D. Hidalgo-Galvez, L. Matías, A. Montero-Ramírez, S. Santolaya, and Ó. Godoy. 2020. Phenological Responses to Climate Change in Communities of Plants Species with Contrasting Functional Strategies. *Environmental and Experimental Botany* 170:103–852. DOI:10.1016/j.envexpbot.2019.103852.

Samoan Society. 1928. The Samoan Division of Time. *Journal of the Polynesian Society* 37:228–240.

Schieffelin, B. B. 2002. Marking Time: The Dichotomizing Discourse of Multiple Temporalities. *Current Anthropology* 43:S5–S17. DOI:10.1086/341107.

Schulze, A., and L. E. Timm. 2012. *Palolo* and *Un*: Distinct Clades in the Genus *Palola* (Eunicidae, Polychaeta). *Marine Biodiversity* 42:161–171. DOI:10.1007/s12526-011-0100-5.

Shuker, K. 2001. *The Hidden Powers of Animals: Uncovering the Secrets of Nature*. Reader's Digest, Pleasantville, NY.

Smetzer, B. 1969. Night of the Palolo. *Natural History* 78:64–71.

Stair, J. B. 1847. An Account of Palolo, a Sea-Worm Eaten in the Navigator Islands, with a Description by J. E. Gray, Esq., F.R.S. Etc. *Proceedings of the Zoological Society of London* 15:17–18.

Stair, J. B. 1897. Palolo, a Sea-Worm Eaten by the Samoans. *Journal of the Polynesian Society* 6:141–144.

Tadataka, I. 2018. Palolo Swarming, Celestial Cycles, and Indigenous Calendrical Systems in Indonesia. 東南アジア研究 [*Southeast Asian Studies*] 55:111–138. DOI:10.20495/tak.55.2_111