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RESEARCH ARTICLE

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How people, rainfall and vegetation shape tropical island fire regimes across Micronesia

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Abstract

Aim: To provide the first regional analysis of contemporary drivers of Pacific Island fire regimes.

Location: Islands of Palau, Yap, Guam, Rota, Tinian, Saipan, Chuuk, Pohnpei, Kosrae.

Time Period: 1950-present.

Methods: We used land cover, soil maps and contemporary fire histories to (1) describe the relationships among fire activity, vegetation, rainfall and island geography and population; (2) examine the spatial associations of forest and savanna vegetation with respect to fire and soil types; and (3) link fire and savanna distribution to intra-annual and inter-annual rainfall variability.

Results: Savanna extent was positively correlated with island age and the range of mean monthly rainfall. The percent of area burned annually reached upwards of 2%–10% of island land areas, correlated positively with rainfall seasonality, and occurred largely within savannas. Savannas were more frequent on acidic soils with higher aluminium than forests but distributed across all soil types. El Niño intensity correlated negatively with dry season rainfall over the entire study region and positively with annual area burned on Guam.

Main Conclusions: The contemporary extents of savannas in Micronesia reflect Pacific Islanders' long-term use of fire to shape vegetation and are modulated by inter- and intra-annual rainfall variability. These relationships provide baseline information for ongoing fire management and mitigation projects throughout Micronesia and critical insight for assessing and anticipating fire risk in other insular areas where fire data are limited.

KEYWORDS
anthropogenic burning, El Niño, fire regimes, forest cover, land cover change, landscape structure, Micronesia, Pacific Islands, savanna, soils

1 | INTRODUCTION

Oceanic Islands provide model systems to understand evolutionary and ecological processes (Vitousek, 2002; Wallace, 2013) and the flourishing of island peoples provide countless examples of highly resilient systems of land and sea stewardship (Komugabe-Dixson et al., 2019; McMillen et al., 2014). Contemporary patterns of fire on oceanic islands have received far less attention than continental regions, but the factors above suggest islands may provide critical insight into the importance of human—fire relationships both for shaping landscapes and living with fire in the future. First, due to the relative rarity of ignitions prior to human arrival, there is strong evidence that fire use by Pacific Islanders was a key driver of landscape change in the past (Athens & Ward, 2004; McWethy et al., 2009; Roos et al., 2016; Stevenson et al., 2017). Second, fire arguably has inordinate influence on Pacific Island ecosystems given their limited land area, high rates of species endemism, relative sensitivity to fire and invasive species, and tight linkages between terrestrial and marine areas (Delevaux et al., 2018; LaRosa et al., 2008; Povak et al., 2020; Trauernicht, Pickett, et al., 2015). The diversity of climates, vegetation and human history on oceanic islands present opportunities to identify the extent to which human burning can influence landscape structure and to integrate fire alongside efforts to increase social and ecological resilience.

Research on contemporary fire regimes on tropical islands tends to focus on negative ecosystem impacts, especially in the context of invasive, fire-prone weeds (LaRosa et al., 2008; Newman et al., 2018; Trauernicht, Ticktin, et al., 2018). This includes foundational work on the grass-fire cycle (D'Antonio & Vitousek, 1992; Hughes et al., 1991) and how fire regimes are linked vegetation change at the watershed scale (Bremer et al., 2018; Ellsworth et al., 2014; Wada et al., 2017). Studies also highlight the need for novel risk assessment methods given unique vegetation and highly variable climates on islands (Trauernicht, 2019; Van Beusekom et al., 2018). Fewer studies engage social dimensions or patterns in the frequency, intensity and extent of burning at island or regional scales (Bubb & Williams, 2022; Dendy, Mesubed, Colin, et al., 2022; Ibanez et al., 2013; Phelps et al., 2022; Trauernicht, Pickett, et al., 2015).

We draw on pyrogeography (Bowman et al., 2011; Krawchuk et al., 2009) as a framework to consider the influence of climate, vegetation, and ignition patterns on fire regimes across nine island groups in Micronesia (Figure 1). Briefly, the likelihood of vegetation to burn is influenced by species composition, climate, and the frequency and distribution of ignitions, the latter being linked to human activities. For instance, aridity limits fire due to low plant productivity (i.e. fuel-limited), whereas perennially wet regions rarely burn (i.e. climate-limited) (Bradstock, 2010; Krawchuk & Moritz, 2011; McWethy et al., 2013). In the tropics, rainfall seasonality promotes fire activity such that it maintains open savanna vegetation where annual rainfall would otherwise support closed-canopy forest (Murphy & Bowman, 2012; Staver et al., 2011). Ignition limitation may occur where lightning is rare or development suppresses fire activity (Archibald et al., 2009). People are often the leading cause of wildfires, through both intentional and accidental ignitions (Balch et al., 2017). People have also skillfully set fires for millennia to achieve multiple ecological outcomes, including burning in early dry season for low intensity fires or late summer so hot fires maintain open habitat (Kimmerer & Lake, 2001; Trauernicht, Brook, et al., 2015). Thus, landscape composition, climate, human activities and their interactions can be used to anticipate fire activity and inform societies seeking to manage fire effects.

The relative rarity of lightning across the Pacific Islands (Albrecht et al., 2016) suggests the region was ignition-limited apart from active volcanoes prior to human arrival. While there is evidence from

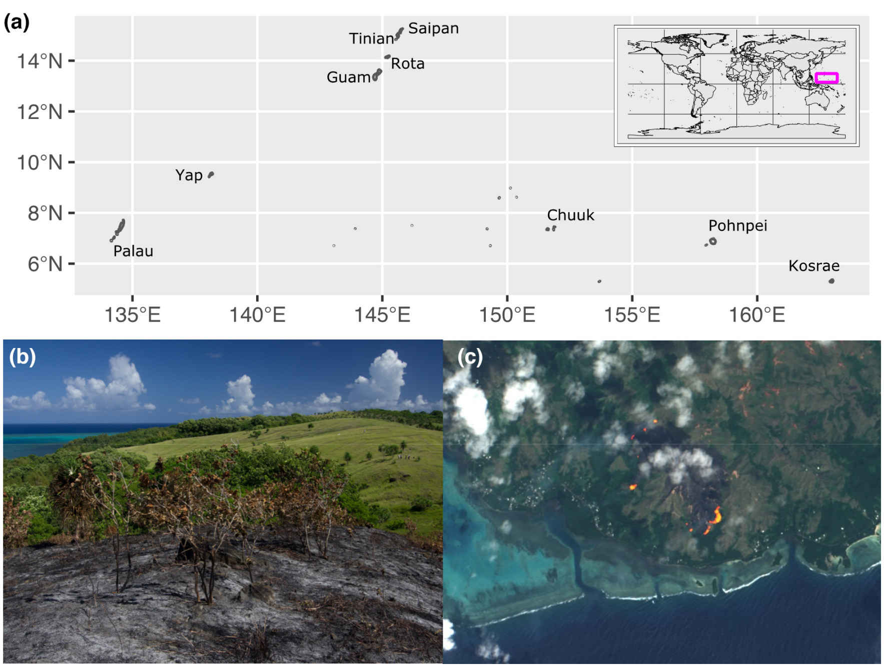

FIGURE 1 (a) Map of study region showing island/island group names. (b) Burned and unburned savanna on Yap with agricultural terrace formations evident in the grasslands and closed canopy forest in the background (photo by C. Trauernicht). (c) Sentinel-2 satellite image from 2019 showing a large fire burning savanna vegetation in the Manell watershed in southern Guam.

Tahiti and New Caledonia of drier climates and increased fire activity altering vegetation during the Pleistocene pre-dating humans (Hope & Pask, 1998; Prebble et al., 2016), there is ample paleoecological evidence linking increases in fire activity to initial human settlement throughout the Pacific. Increases charcoal and the pollen of grasses and other secondary vegetation is contemporaneous with human arrival on many Polynesian islands including Fiji, Tonga, Tahiti, Rapa Nui and Aotearoa (New Zealand) within the past several thousand years (Fall, 2010; Hope et al., 2009; McWethy et al., 2009; Stevenson et al., 2017). Similarly, paleoecological work from Guam, Yap and Palau in Micronesia show large increases in charcoal and pollen from savanna-restricted grasses and ferns that coincide with human arrival c. 4000 years ago (Athens & Ward, 2004; Dickinson & Athens, 2007; Dodson & Intoh, 1999; Welch, 2002). This evidence contrasts with continental regions, where attributing savanna expansion to fire use has been more difficult (Marlon et al., 2013; Rowe et al., 2019).

The contemporary, widespread distribution of fernlands and grasslands across Pacific Islands indicate that the "transported landscapes" spread throughout the region by Pacific Island people were closely linked to fire use for agriculture and other purposes (Kirch, 1982; Mueller-Dombois & Fosberg, 1998). For example, landscape reconstructions in Aotearoa also indicate that current expanses of fern- and shrublands are attributable to Māori fire use beginning c. 800 years ago (McWethy et al., 2009; Perry et al., 2012). In Hawai'i, contemporary fire and vegetation patterns link directly to human activity with 98% of ignitions being human-caused and increases in area burned correlated with the expansion of non-native grasslands across former agricultural lands (Trauernicht, Pickett, et al., 2015). In Micronesia, escaped agricultural fires and landscape burning attributed to hunting and accessing other food resources characterise modern fires on Guam, Rota, Saipan and Palau (Dendy, Mesubed, Colin, et al., 2022; Minton, 2006). On Yap and Palau, pre-contact agricultural terracing and ditch systems remain visible and are widespread within savanna landscapes, also potentially linking fire to land use change and agricultural abandonment (Liston, 2009; Smith, 1983).

There may be constraints on the landscape effects of human fire use. There is little evidence for vegetation change coincident with increasing fire after people arrived in Samoa, for example, (Gosling et al., 2020) and forests appear to reestablish as humans abandoned coastal sites in Tahiti (Stevenson et al., 2017). The outcomes of burning likely changed over time as well due to both changes in fuels and purpose from initial burning to, for example, clear land for farming, and subsequent fires used intentionally to maintain open landscapes (Kimmerer & Lake, 2001; Trauernicht, Brook, et al., 2015). Hunter-Anderson (2009) attributes Micronesian savannas to mid-Holocene drying, while Dodson and Intoh (1999) suggest low-fertility soils and savanna-restricted endemic species indicate savannas were widespread before humans. Fertilisation trials on Palau and Yap illustrate that nutrient deficiency limits tree growth but not necessarily tree establishment in savannas (Dendy et al., 2015; Friday et al., 2021). Research from continental savannas indicate that climate and

TABLE 1 The features of Micronesian high islands/island groups considered in the context of fire regimes and examined in correlation plots.

Island group	Island age (MY)	Last active volcano (MYBP)	Human arrival (YBP)	Current Pop. (pp/km^{-2})	Land area (km^2)	Tot. Forest cover (%)	Secondary Forest cover (%)	Savanna cover (%)	Forest exposure	Reburn Freq. (%)	Mean annual rainfall (mm)	Rainfall season-ality index
Kosrae	9	1	1000	59.4	111.3	94.8	9.1	1.1	14.1	NA	1933	0.11
Pohnpei	9	1	2000	97.4	371.6	94.9	11.7	3.0	26.5	NA	1813	0.09
Chuuk	15	5.5	2000	400.4	121.5	89.1	35.9	2.7	14.9	NA	1345	0.12
Guam	30	32	3200	294.7	549.0	42.1	16.4	28.2	67.0	25.6	976	0.49
Saipan	30	23	3200	405.1	118.9	58.1	17.7	12.9	35.5	47.8	698	0.54
Tinian	30	23	3200	30.2	101.2	76.9	21.1	7.8	30.4	26.2	787	0.53
Rota	30	8	3200	31.0	85.1	66.3	14.5	17.4	30.0	40.1	912	0.45
Yap	11	7	3300	95.2	119.5	79.9	35.3	12.2	16.7	9.4	1209	0.32
Palau (Babeldaob)	37	20	4300	19.6	331.0	86.3	15.3	9.6	42.1	17.7	1476	0.18

Note: For Rainfall Seasonality Index, larger values indicate greater temporal concentration of rainfall. Palau statistics are for the island of Babeldaob, which makes up 71% of Palau's land area (see Section 2).

fire are stronger limiting factors than soils for tree establishment (Bond, 2010; Murphy & Bowman, 2012; Scholes & Archer, 1997) and Micronesia receives adequate rainfall for forest development on even the driest islands (≥700 mm $year^{-1}$; Table 1).

Other factors complicate interpretations of Pacific Island savanna distribution. Paleoecological work indicates that agriculture and introduced rats may be most responsible for early forest declines on some islands (Athens, 2008; Prebble & Wilmshurst, 2009). Contemporary research clearly points to the direct impacts of introduced rodents and ungulates on forest declines due to seed consumption and herbivory as well as their indirect impacts on native pollinators, seed dispersers, and sea-to-land nutrient flows due to seabird predation (Fukami et al., 2006; Leopold & Hess, 2017; Perry & Morton, 1999; Rowe et al., 2017; Shiels & Drake, 2015). Modern era colonialism further led to deforestation via grazing, phosphate mining, copra production, sugar, and other plantation crops (Firth, 1973; Knapman, 1985). Many Pacific Islands, including Pohnpei, Chuuk, Guam, Rota, Tinian, Saipan and Babeldaob in Palau considered in this paper, were also heavily impacted by Japanese and American bombing and other related damage (e.g. mining) during World War 2 (WW2), followed by revegetation efforts on some islands via aerial seeding (Perry & Morton, 1999).

Savanna vegetation in Micronesia ranges from the *Dicranopteris* fern-dominated savannas with mixed shrubs and graminoids, similar to *talāsiga* on Fiji and *taofa* or *kula* in Tonga and Samoa (Morrison, 2019; Whistler, 1992) and frequently encountered on Palau and islands of the Federated States of Micronesia, to nearly monotypic swordgrass (*Miscanthus floridulus*), common across the Mariana Islands (Mueller-Dombois & Fosberg, 1998). Unlike vast non-native grasslands in Hawaii (Trauernicht, Pickett, et al., 2015), Micronesian savannas are largely dominated by indigenous species, although there are concerns with invasive species such as *Imperata cylindrica* and some sources consider *M. floridulus* invasive on Guam (Reddy, 2011). Pacific Island savannas are frequently described as "degraded" in the scientific literature due to their lower species diversity relative to forest, low soil fertility, and association with anthropogenic disturbance (Friday et al., 2021; Povak et al., 2020). However, some savannas are valued locally as sources of medicinal plants (A. Singeo, pers. obs.) (Balick & Kitalong, 2021) and are habitat for several endemic birds (Merlin & Raynor, 2005). Savanna fires increase erosion rates which can impact nearshore ecosystems (Minton, 2006), however large erosion scars (i.e. "badlands"), road cuts like the "Compact Road" on Babeldaob, Palau and off-road vehicles appear to be larger contributors to sedimentation (Povak et al., 2020; Shelton & Richmond, 2016; Victor et al., 2004). Variation in savanna composition among islands may also influence fire risk such as the large fuel loads documented in *M. floridulus* grasslands (e.g. 1300–2000 $g\,m^{-2}$ or 5–9 tons $acre^{-1}$) (Minton, 2006; Mueller-Dombois & Fosberg, 1998).

To contribute to a broader perspective of people, land cover, climate, and fire on oceanic islands, we use pyrogeography as a framework to examine and compare nine island groups in Micronesia spanning >3000 km across the equatorial Pacific Ocean, including Palau, Guam, Saipan, Rota, Tinian, Yap, Chuuk, Pohnpei, and Kosrae (Figure 1). Our objectives were to: (1) Describe the relationships among contemporary fire activity, vegetation, rainfall, and island geography and population across the region; (2) examine the spatial associations of forest and savanna vegetation with fire and soil types; and (3) use regional rainfall variability to examine the extent to which fire and savanna distribution are climate-limited in terms of both annual and seasonal rainfall variability. Our approach is largely descriptive, yet quantifying the frequency and extent of fire and examining the influence of multiple factors on fire and vegetation is a critical need for the region (Bubb & Williams, 2022; Dendy, Mesubed, Colin, et al., 2022; Trauernicht, Pickett, et al., 2018). This work directly contributes to community and agency efforts to better integrate fire risk and planning into ecosystem and community protection in Pacific island landscapes. In addition, by exploring a range of landscapes and climates over the region, our analyses provide fundamental insight into how the ecological effects of human fire use may be constrained by other factors.

2 | MATERIALS AND METHODS

2.1 | Study area

We considered the high islands of Micronesia including the Federated States of Micronesia (FSM; Kosrae, Pohnpei, Chuuk and Yap), the Republic of Palau (Babeldaob Island), and Guam, Rota, Tinian, and Saipan in the Mariana Islands (Figure 1a). High islands are distinguished from atolls in the region in being primarily volcanic in origin with some areas of uplifted limestone, and having larger extents and more diverse topography. Fire is most prevalent among the westernmost islands, which experience distinct dry seasons (see below). In the wetter, eastern islands, persistent savanna vegetation, anecdotal accounts of cultural burning, and large fires tied to drought (van der Brug, 1985) provide an opportunity to examine climatic limitations on fire across the region. The islands range from c. 240–650 m elevation and from 9 to >30 million years old with no volcanic activity for at least 1 million years (Table 1; Neall & Trewick, 2008; Rehman et al., 2013). The four main islands of Yap and the 14 high islands within Chuuk lagoon were considered as single "study units." For Palau we considered only Babeldaob, the largest island of volcanic origin in the archipelago.

Human arrival dates to 3–4000 years ago among the westernmost and 1000–2000 years ago for Pohnpei and Kosrae (Table 1; Clark et al., 2006; Intoh, 1997; Petchey et al., 2017). Early European contact dates to the 1500s but colonisation and integration into global markets occurred in the mid- to late 1800s in the Federated States of Micronesia and Palau (Hanlon, 2009). Guam and to a lesser extent the northern Marinas were colonised by Spain starting in the 1600s. Except for Guam, which the U.S. claimed as a Territory following the Spanish-American War in 1898, current political designations were determined following the end of Japanese administration after WW2. Rota, Tinian and Saipan form the Commonwealth of the

Northern Mariana Islands, an unincorporated territory of the U.S. The Republic of Palau and the FSM are independent nations that maintain a "Compact of Free Association" with the U.S. Intensity of development in the region ranges from highly developed tourism on Guam (which also supports a large number of US military personnel and infrastructure), Saipan and Palau, to relatively little outside investment in Rota, Tinian, Yap, Pohnpei and Kosrae, where people rely on U.S.-funded civil servant jobs, remittances from family working abroad, and subsistence farming and fishing. Current population density ranges from moderately high (c. 300–400 ppL/km^2) in Guam, Saipan, and Chuuk to relatively low (c. 20–90 ppL/km^2) across the other islands (Table 1).

The region is considered a biodiversity hotspot with high levels of island endemism and diverse forest and reef ecosystems (Costion & Lorence, 2012; Dendy et al., 2015; Mueller-Dombois & Fosberg, 1998). Large areas of forest on some islands (e.g. Guam, Tinian and Saipan) are dominated by *Leucaena leucocephala*, a fire- and disturbance-adapted small tree native to Central America, which was aerially seeded across the Mariana Islands to mitigate bombing impacts during WW2. Extensive areas of some islands also consists of diverse agroforests with *Artocarpus altilis*, *Cocos nucifera*, *Musa* spp. and other species cultivated for food, fibre and medicine for millennia. All islands also have open savanna vegetation dominated by native ferns (e.g. *Dicranopteris*) and shrubs as well as native and non-native grasses (Costion & Lorence, 2012; Figure 1b,c).

Mean annual rainfall ranges from >1800 mm year^{-1} in Kosrae and Pohnpei to 700–900 mm year^{-1} across the Mariana islands. Precipitation in Micronesia is driven by variations in the Intertropical Convergence Zone (ITCZ), the El Niño-Southern Oscillation (ENSO), trade winds, and the North Pacific Subtropical High (Heim et al., 2020). More western islands are influenced by the East Asian Monsoon and the Western North Pacific Monsoon which result in pronounced dry seasons from January to June in the Mariana Islands, slightly less seasonality in Yap and Palau, and very low seasonality for Chuuk, Pohnpei and Kosrae (Table 1). Severe droughts are often associated with El Niño events as rainfall is shifted away from the western Pacific (Frazier et al., 2019; Heim et al., 2020; Iese et al., 2021).

2.2 | Data sources

We used fire histories developed for Palau, Yap, Guam, Rota, Tinian, and Saipan by the USDA Forest Service Pacific Southwest Research Station's Institute of Pacific Islands Forestry in Hilo, Hawai'i (Dendy et al., 2023; Dendy, Mesubed, Giardina, et al., 2022). These datasets provide spatial fire perimeters dated to month and year from Digital Globe satellite imagery from 2012 to 2021 for Babeldaob island on Palau, 2015–2021 for Guam, and 2016–2021 for all other islands. For non-spatial analyses we included annual area burned data derived from GPS and aerial photos from 1979 to 2002 for Guam provided by Guam Forestry (Minton, 2006) and from 2012 to 2015 for Yap provided by Yap Forestry. LANDFIRE Existing Vegetation Type (EVT; 30 m resolution) was the only high resolution land cover product including all islands and used to assess land cover and the distribution of fires across vegetation types (Ryan & Opperman, 2013). This product was updated from 2016 imagery for insular areas (released in 2021) and major changes in land cover categories from the prior 2010 version preclude tracking potential shifts in land cover due to fire. To facilitate analyses and visualisation, we simplified land cover from 26 to the flowing nine classes: "Limestone forest", "Mangrove forest", "Other native forest", "Secondary dry woodland", "Shrubland/scrub", "Secondary forest/plantation", "Savanna", "Agriculture" and "Other" (see link to analyses below). Forest types reflect key differences in species composition due to disturbance and soils/parent material.

Soils data came from the US Department of Agriculture National Resource Conservation Service Soil Survey Geographic database (NRCS-SSURGO), which provide spatial data on soil taxonomy and soil properties by horizon for all islands under consideration (USDA-NRCS, 2023). Monthly rainfall averages came from weather station data provided by the National Weather Service Pacific Islands Drought Monitor group (Heim et al., 2020; www.drought.gov), from which we calculated rainfall seasonality on a 0–1 scale as the sum of the absolute deviations of mean monthly rainfalls from the overall monthly mean, divided by the mean annual rainfall, with larger values indicating greater temporal concentration of rainfall (Walsh & Lawler, 1981). Since this index does not specify the timing of rainfall seasonality, we also examined monthly area burned in relation to the percentage of mean annual rainfall per month for each island (see below). We used station-based daily rainfall data from Palau, Guam, Yap, Saipan and Pohnpei obtained from the U.S. National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) to examine relationships of dry season rainfall and El Niño events (see below). NASA's Global Hydrology Resource Center's gridded lightning climatology (strikes km^{-2} year^{-1} from 1998 to 2013) was used to examine Pacific Island versus global lighting activity (Albrecht et al., 2016). Other island-specific variables that were considered included island size, geologic age (Neall & Trewick, 2008; Rehman et al., 2013), time since human arrival (Clark et al., 2006; Intoh, 1997; Petchey et al., 2017), and population density (The Pacific Community, 2022; US Census Bureau, 2015) (see Table 1).

2.3 | Analyses

All analyses used R and can be found at https://github.com/claytrau/micronesia_fire_analyses/ along with associated data tables and links to spatial data sets cited above (R Core Team, 2022). We used simple correlations and the package "corrplot" to explore the relationships between various geologic/geographic, climatic and social factors summarised per island/island group (Table 1) and land cover, using the contemporary extents of forest and savanna, as well as fire regimes (Wei & Simko, 2021). For geologic and geographic variables, we calculated all pairwise correlations among percent forest cover, percent savanna cover, island size, island age and time since human arrival. For climatic variables, we looked at correlations among percent forest cover, percent savanna cover, mean annual rainfall, minimum monthly rainfall and range, or difference between the maximum and minimum, of mean monthly rainfall. For fire-related correlations, we considered the median percent area burned per year, the median count of fires per year, percent savanna cover and rainfall seasonality. Fire-related correlations only included Palau, Yap, Guam, Rota, Tinian and Saipan, where fire histories were available. To examine lightning density, we used boxplots (along an inverse hyperbolic sine scale) of 500 randomly sampled pixels each for the entire lightning climatology (Global), for all Pacific Islands and for the study region (Micronesia) using offshore political boundaries available from the Natural Earth Collection (Patterson & Kelso, 2012).

Spatial fire histories were used to plot fire size distributions for each island using boxplots along a log scale. We used jitter plots in the R package "ggplot2" to examine raw values of annual percent of land area burned and annual count of fires per island using all available fire data (Wickham, 2016). For context, we compared annual percent land area burned with both Hawai'i (www.pacificfireexchange.org/region/hawaii; Trauernicht, Pickett, et al., 2015) and the 12 westernmost states on the US continent (including Alaska) using data from the National Interagency Fire Center (www.nifc.gov). Island fire perimeters and mean monthly rainfall were also used to compare monthly area burned (median, minimum, and maximum) and the percentage of annual rainfall per month by island. Fire perimeters and the LANDFIRE EVT product were used to examine annual variability in the distribution of area burned across land cover type by island using the "raster", "sf", "sp", "rgdal" and "exactextractr" R packages (Baston, 2022; Bivand et al., 2022; Hijmans, 2022; Pebesma, 2018; Pebesma & Bivand, 2005). We also used LANDFIRE EVT to calculate a relative "forest exposure" value for each island by determining the actual length of forest edge adjacent to savanna (as 30-m pixels) relative to the minimum possible forest edge if current savanna extent occupied a single, contiguous circular area: Forest exposure = (forest edge length-minimum edge length)/minimum edge length. We overlaid annual fire perimeters to visualise the distribution and frequency of fire and calculated a "reburn frequency" as the percentage of total area burned recurring in the same locales for two or more years.

We compared soil taxonomy (soil orders), pH, organic matter, the sum of extractable bases and extractable aluminium by sampling NRCS-SSURGO data from an equal number of random points in savannas and native forest (excluding mangrove) derived from LANDFIRE EVT classifications across all islands using the R packages "raster", "rgdal", "sf" and "sp" (Bivand et al., 2022; Hijmans, 2022; Pebesma, 2018; Pebesma & Bivand, 2005). The distribution of savanna and forest points across major soil orders were compared visually for each island and tested for differences by grouping all island data together using a chi-squared test. The other properties were examined for surface soils only (O and A horizons) and each variable was modelled as a function of land cover (forest vs. savanna) and island using a linear generalised additive model (i.e. no smoothing functions) using the "mgcv" package in R which enabled the incorporation sample coordinates to account for spatial autocorrelation (Wood, 2011). We used multi-model selection and Akaike's information criterion to identify the best supported models relative to the null with the R package "MuMIn" (Bartoń, 2022). Analyses of pH and organic matter included all nine islands with sample sizes per cover type per island limited to the maximum number of savanna samples on Kosrae ($N = 92$; total $N = 1656$). The sum of extractable bases and extractable aluminium were only available for Guam and Palau where 200 random samples per land cover type per island were used ($N = 800$). All variables except for pH were transformed using different root functions to meet assumptions of normally distributed model residuals.

We also explored the linkages between El Niño intensity, rainfall and fire. We fit a linear model of mean dry season (defined as January–June) values of the Multivariate ENSO Index (MEI) (Zhang et al., 2019) with annual percent of land area burned for Guam, which provided the longest available fire history (i.e. 1979–2002 and 2015–2021; see above). We also used longer term, continuous rainfall data (1950–2019 for Guam, 1989–2019 for Saipan, and 1952–2019 for all others) to fit linear models of annual "dry season" precipitation (total rainfall from January to June) as a function of dry season MEI for Guam, Palau, Saipan, Pohnpei and Yap.

3 | RESULTS

Plotting mean annual rainfall, rainfall seasonality and percent annual area burned by island illustrated how fire is most prevalent among the driest islands but also correlates with greater rainfall seasonality such as on the wetter islands of Yap and Palau (Figure 2a). The distributions of lightning density showed that Pacific Islands generally have low lightning activity relative to global values, with a median of zero and maximum of 3 strikes $km^{-2} year^{-1}$ for Micronesia (Figure 2b). We therefore excluded lightning data from the correlations described above. Fire size distributions were consistent across islands, with fire regimes dominated by small fires with median values between 0.5 and 2 hectares (Figure 2c). Percent cover of savanna vegetation per island showed moderate positive correlations with island age ($r = 0.58$) and time since human arrival ($r = 0.57$), indicating greater prevalence of savanna on older and the more westward islands, which were settled earlier (Figure 1d). Savanna extent was also negatively correlated with mean annual ($r = -0.63$) and minimum mean monthly rainfall ($r = -0.71$) and strongly and positively correlated with range in mean monthly rainfall ($r = 0.94$; Figure 2e). In general, percent total forest cover showed opposite and slightly weaker correlations with these variables (Figure 2d,e). Median annual percent area burned was positively correlated with savanna cover ($r = 0.59$) and rainfall seasonality ($r = 0.78$; Figure 1f). The median number of fires per year was also positively correlated with savanna cover ($r = 0.85$) and population density ($r = 0.36$). Forest cover was lowest on the drier islands of Guam (42%), Rota (66%), Saipan 58%) and Tinian (77%), followed by Yap (80%), Palau (86%) and Chuuk

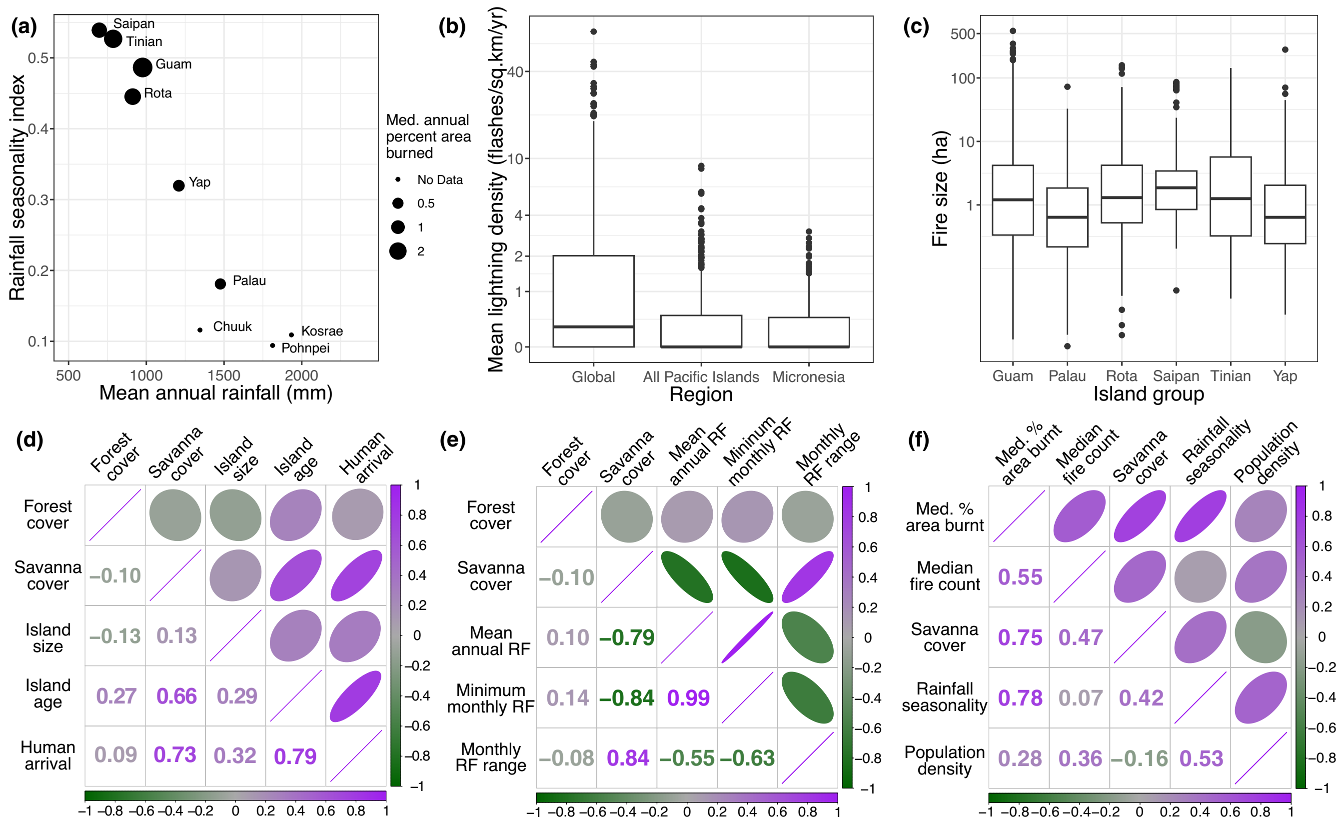

FIGURE 2 Summaries of fire-related variables and correlations across the region, including: (a) all island groups considered in the analyses plotted along mean annual rainfall and rainfall seasonality index with point size indicating the median area burned as a percentage of total land area; (b) distributions of lightning density (mean flash count km^{-2} year^{-1}) globally, for all Pacific Islands, and for the study region (Micronesia) using data from NASA's Global Hydrology Resource Center (1998–2013) plotted on an inverse hyperbolic sine scale; (c) fire size distributions for islands with fire records plotted on a log scale. The lower panels present correlations among features summarised per island group for (d) geological and geographical variables and percent forest and savanna cover for all islands; (e) climatic variables and percent forest and savanna cover for all islands; and (f) fire regimes using median percent area burned per year and number of fires per year, excluding Chuuk, Pohnpei, and Kosrae due to lack of fire records.

(89%), and highest on the wettest islands of Kosrae and Pohnpei (95%; Table 1; Figure 3). Conversely, the westernmost islands of Palau, Yap and the Marianas supported greater savanna covers (10%–28% of total land area) than the eastern islands of Chuuk, Pohnpei and Kosrae (1%–3%; Table 1; Figure 3). Even over brief fire histories, there was a high tendency for fires to recur in the same locales, largely in savannas (Figure 3), with reburn frequencies highest for Saipan (48%) and Rota (40%) and lowest for Palau (18%) and Yap (9%; Table 1).

The percent land area burned and number of fires per year were highly variable within and between islands (Figure 4). Guam had the highest values for both metrics, with as much as 10% of the island burning and nearly 2000 fires during the most active fire years. (Figure 4a,b). The annual percentage of land area burned on all the other islands greatly exceeded both Hawaii and the Western US (Figure 4a). Rota and Yap were comparable to Guam with 7% of total land area burning in the most active fire years. Area burned by month illustrates the seasonality of fire occurrence during drier months (Figure 5a). Peak fire activity in Guam, Palau and Yap were in March, whereas Rota, Tinian and Saipan peaked later in the dry season in May and June (one of Rota's largest fires occurred in July 2019). Yap and Palau have more evenly distributed monthly rainfall (seasonality indices of 0.32 and 0.19, respectively). Palau's monthly rainfall was slightly bimodal with smaller peak of fire activity in September and October (Figure 5a). For most islands, 50% to 90% of annual area burned intersected with savanna (Figure 5b). Secondary dry forest/plantation and dry woodland were the next most frequently burned areas accounting for upwards of 40% in some years. Tinian and Yap had the largest areas of native forest intersecting with burned areas (c. 30%; Figure 5b).

Both savanna and forest occurred on all major soil orders found on the islands but a chi-squared test indicated significant differences between land covers ($X^2 = 80.86$; $p < 0.005$). Savanna sample sites tended to be more frequently associated with Oxisols while forests with Entisols and Alfisols, but patterns were not consistent across islands (Figure 6a). Mollisols for example, were more frequently associated with savanna on Guam and Rota, forests on Saipan, and evenly distributed between land cover types on Kosrae and Tinian. Both island and land cover (forest vs. savanna) were supported as predictors of all four soil properties, with interaction terms supported for all

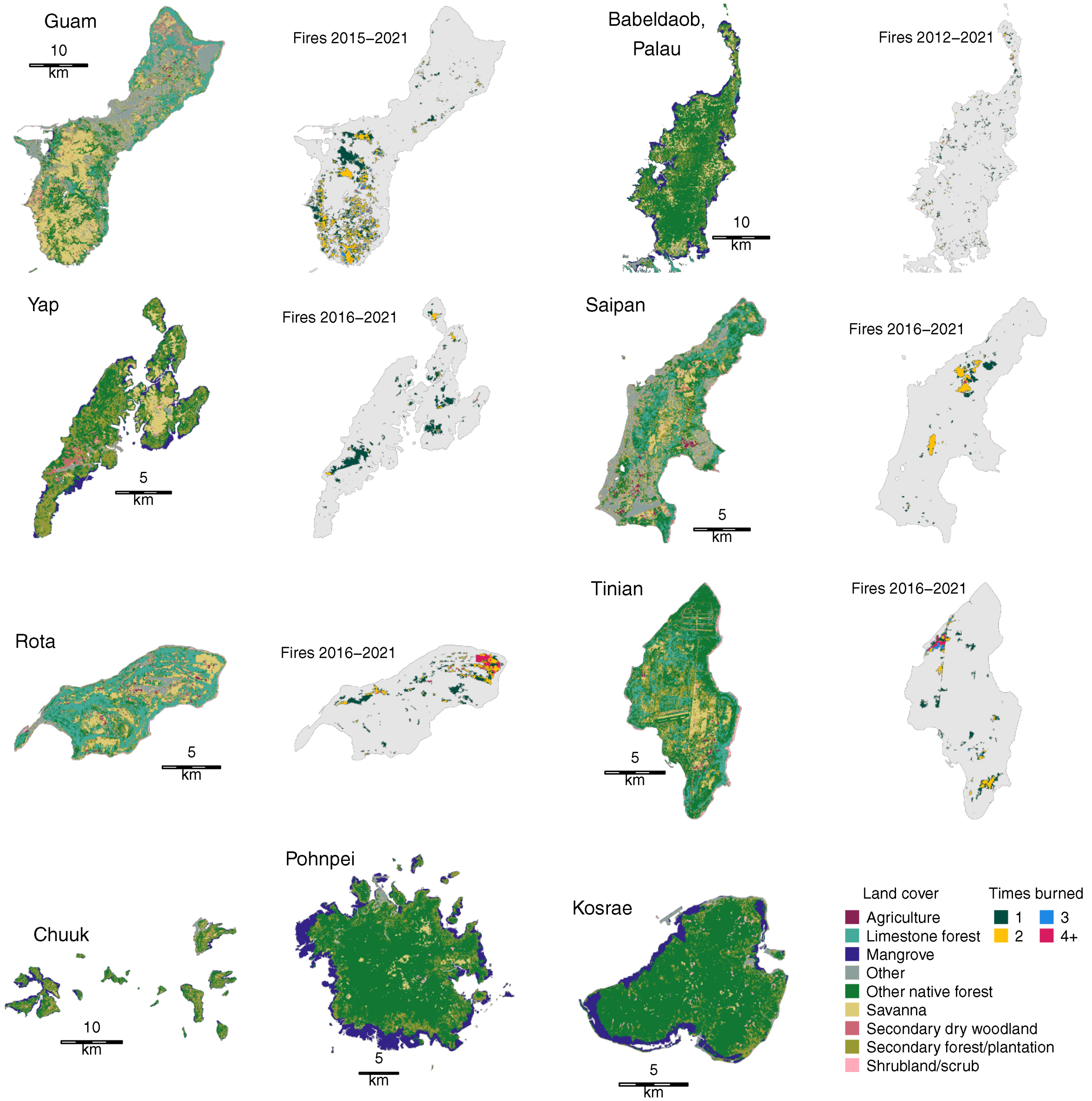

FIGURE 3 Land cover from 2016 LANDFIRE Existing Vegetation Type for all high islands in Micronesia and the extent of contemporary fire perimeters overlaid as times burned per 30 m pixel for islands with available data.

but extractable aluminium (Soil pH: Explained deviance (D^2) = 58.7%, Akaike Weight (w_i) > 0.99; Soil organic matter D^2 = 51.4%, w_i > 0.99; Sum of extractable bases: D^2 = 37.0%, w_i = 0.87; Extractable aluminium: D^2 = 15.5%, w_i = 0.72; Figure 6b–e). Savanna soils trended lower with respect to pH and organic matter, but these differences were only pronounced on Guam and Yap (Figure 6b). Savanna soils tended to be less acidic on Chuuk and Palau. Differences between forest and savanna sites for organic matter were undiscernible for most islands (Figure 6c). Guam savannas had lower values for the sum of extractable bases, but Palau savannas tended towards higher values (Figure 6d). Extractable aluminium was clearly higher in savanna sites on both Guam and Palau (Figure 6e).

Fitting linear models of fire and rainfall as a function of MEI supported the influence of El Niño events on both fire activity and precipitation over the entire region (Figure 6). Percent area burned annually on Guam had a clear, positive relationship with El Niño intensity as depicted by the dry season MEI (R^2 = 0.45; Figure 7a). Longer term rainfall records demonstrated negative linear relationships between MEI and dry season rainfall for Guam (R^2 = 0.15), Palau (R^2 = 0.34), Saipan (R^2 = 0.31), Pohnpei (R^2 = 0.19), and Yap (R^2 = 0.42),

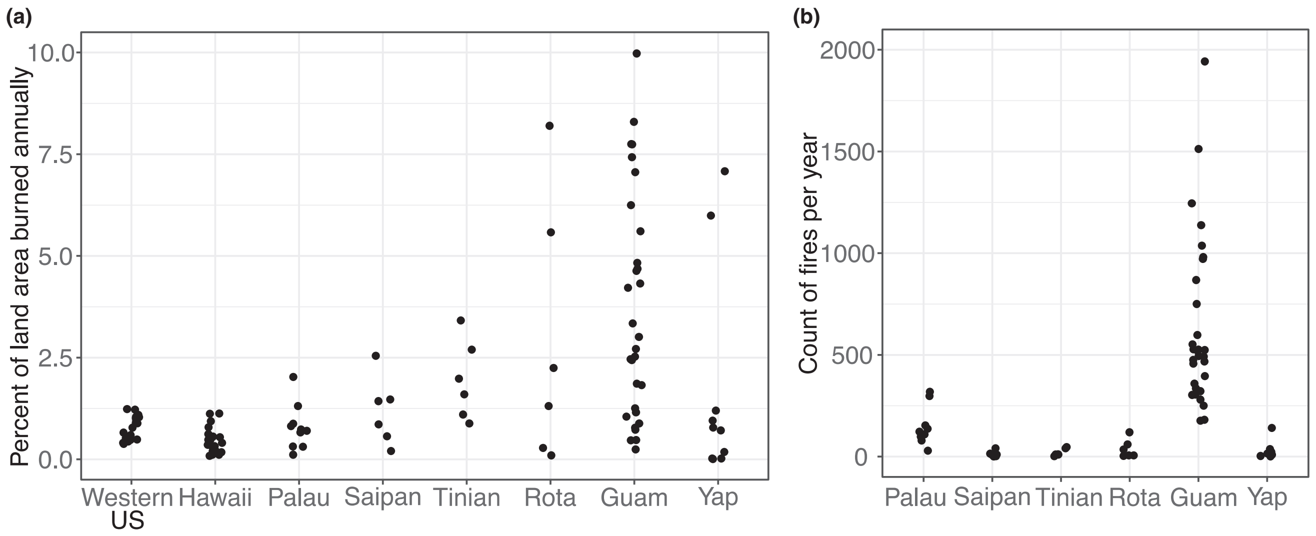

FIGURE 4 The (a) percent of total land area burned for each island/island group as well Hawaii and the 12 westernmost states on the US continent (including Alaska) and (b) count of fires per year per island/island group.

indicating similar effects of El Niño on rainfall, and thus potential fire activity, for seasonally dry and wet islands alike.

4 | DISCUSSION AND CONCLUSIONS

Our results demonstrate how prevalent fire can be on Pacific Island landscapes and provide insight into the factors shaping fire activity at a regional scale. Our use of simplified land cover (i.e. savanna vs. forest) drew on established interdependencies between savannas and fire demonstrated globally (Murphy & Bowman, 2012; Staver et al., 2011) as well as prior island studies (Bubb & Williams, 2022; Dendy, Mesubed, Colin, et al., 2022; Goel et al., 2020; Ibanez et al., 2013; Phelps et al., 2022; Trauernicht, Pickett, et al., 2015). Briefly, the positive feedback between fire and open, grassy, shrub- or fern-dominated vegetation allows savannas to establish and persist in regions climatically suited for tropical forest, creating heterogenous landscape mosaics at multiple spatial scales. The co-occurrence of closed canopy forest alongside savannas evident in contemporary land cover (Figure 3), the high reburn frequencies on many islands (Table 1), as well as the pollen and charcoal records (Athens & Ward, 2004; Dodson & Intoh, 1999) indicate similar dynamics influence landscape structure in Micronesia.

The study region encompasses a range of conditions that provide insight into key aspects of global pyrogeography. Although ignitions are dependent on human activities on Micronesian islands, the extent of fire is not clearly linked to patterns in human settlement. Correlations among percent area burned, count of fires and population density were not strong (Figure 2f). This is further reflected by relatively low numbers of fires on Rota, Tinian and Yap that still result in extensive area burned in some years (Figure 4a,b). It is likely that longer-term changes in human settlement changed fire patterns that our short-term analysis cannot capture. For instance, agricultural terracing and ditches in savannas on Palau and Yap (Figure 1b; Dodson & Intoh, 1999; Liston, 2009) may indicate an expansion of fire-prone vegetation due to agricultural abandonment, which is a key driver of increasing contemporary fire activity in Hawaiʻi (Trauernicht, Pickett, et al., 2015). The extent of former agricultural areas on Pacific Islands only increases as new LIDAR research emerges (Bedford et al., 2018; Jackmond et al., 2019) and while burning may have coincided with early agricultural intensification (Fall, 2010; Prebble & Wilmshurst, 2009; Roos et al., 2016) evidence from Kosrae suggests complex agroforestry systems emerged after burning and forest degradation (Athens et al., 1996). Conversely, contemporary development may increase fires associated with land clearing for agriculture and hunting (Dendy, Mesubed, Colin, et al., 2022) such as with the "Compact Road" encircling Babeldaob Island in Palau (A. Singeo, pers. obs.). This historical and site-specific context highlights the critical importance of local knowledge about the motivations for fire use and anticipating where land use change may increase fire risk for ecosystems and communities.

In terms of climate, Micronesia covers a range of rainfall quantity and seasonality, the latter factor being most correlated with both savanna extents and fire activity (Figure 2a,e,f). Even with moderately higher seasonality, savanna extents on Palau and Yap were an order of magnitude greater than Chuuk, Pohnpei and Kosrae (Figure 2a; Table 1). The persistence of Micronesian savannas despite suitable rainfall for forest development aligns with the notion of savannas as alternative stable states maintained by recurrent fire (Goel et al., 2020; Murphy & Bowman, 2012; Staver et al., 2011). The key factor distinguishing island fire regimes and savannas from continental systems is the "release" from an ignition-limited condition upon human arrival, as indicated by both the paleoecology and low lightning activity (Figure 2b). However, attributing contemporary savanna extents to human burning remains debated in both continental and island systems (Bowman et al., 2011; Hunter-Anderson, 2009; Iriarte et al., 2012; Nunn, 1997; Trauernicht, Brook, et al., 2015). The dominance of native plant species in many

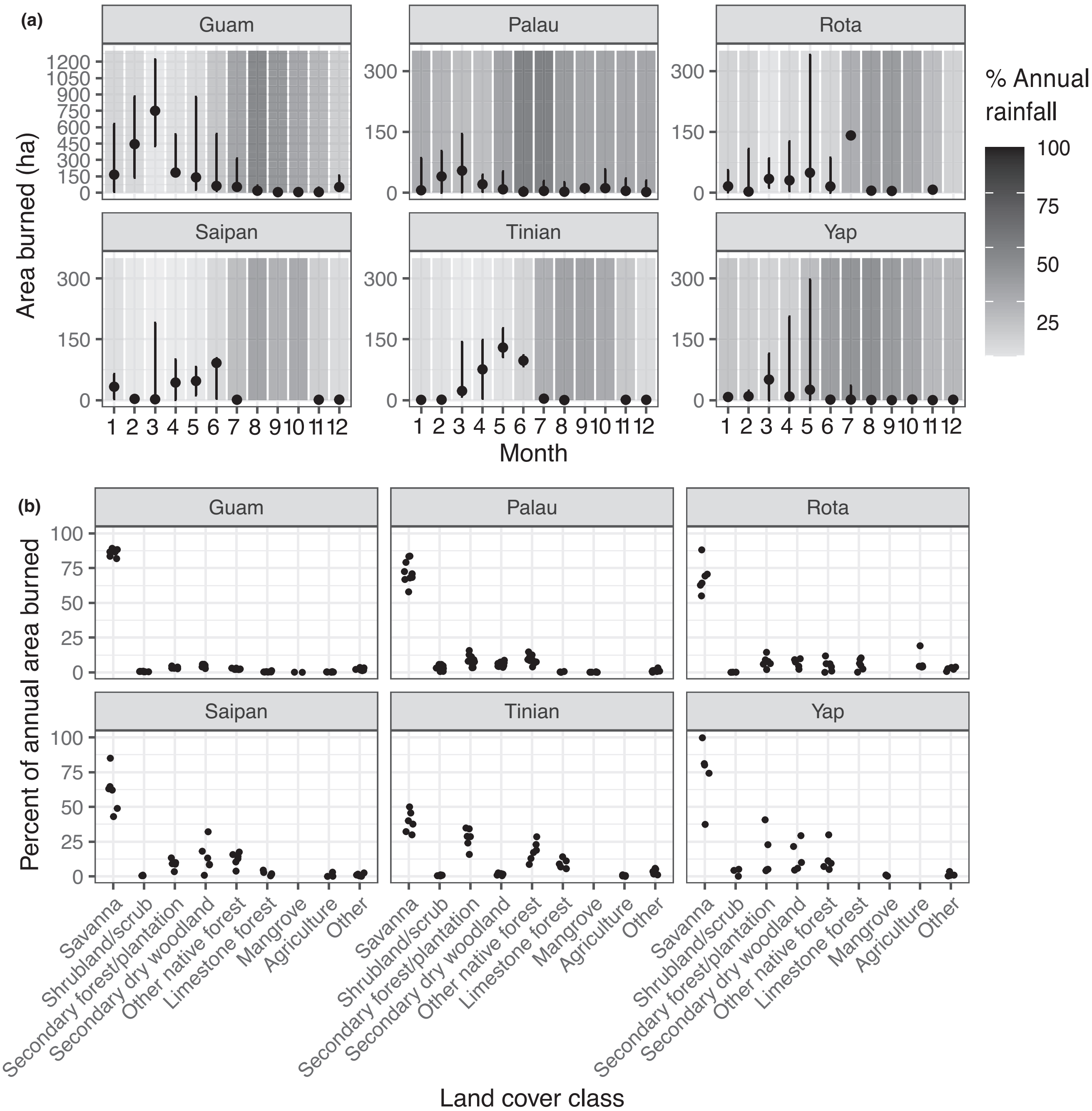

FIGURE 5 Panels showing (a) median, maximum and minimum area burned overlaid on the percentage of annual rainfall per month and (b) the distribution of burned area across simplified land cover types (from LANDFIRE) for islands with available fire perimeter data.

savannas is broadly interpreted as evidence that these ecosystems existed on Pacific Islands prior to people (Hope et al., 2009; Morrison, 2019; Mueller-Dombois & Fosberg, 1998; Nunn, 1997; Prebble et al., 2016). Paleoecological evidence from New Caledonia indicates savannas may have expanded due to fire under a drying climate during the Pleistocene (Hope & Pask, 1998; Stevenson et al., 2001). Yet the pollen record also indicates forest recovery prior to human arrival in New Caledonia (Stevenson et al., 2001) and afterwards in abandoned coastal sites on Mo'orea, Tahiti and where land use transitioned to cultivated agroforests on Kosrae (Athens et al., 1996; Stevenson et al., 2017). Given the overwhelming evidence linking human arrival and increases in fire activity and savanna plant abundance across the Pacific (Athens & Ward, 2004; Dickinson & Athens, 2007; Dodson & Intoh, 1999; Fall, 2010; Hope et al., 2009; McWethy et al., 2009; Stevenson et al., 2017; Welch, 2002), the current distribution of Pacific Islands savannas provides clear evidence of the degree to which people can shape landscape structure and composition via fire.

The ecology of Micronesian savannas has received far less attention than forests (Dendy et al., 2015; Dendy, Collins, Mesubed,

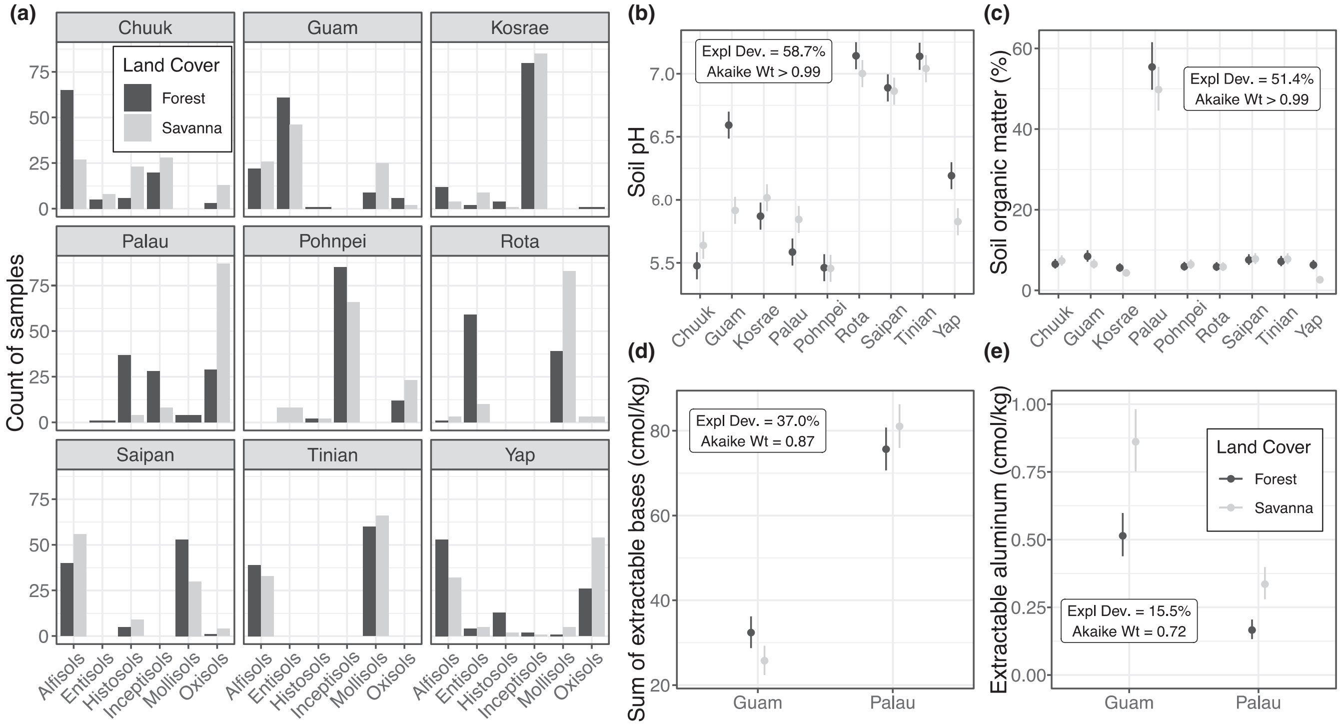

FIGURE 6 Comparisons of soil properties of Pacific Island savannas and native forest (excluding limestone and mangrove forest) illustrated by (a) the distribution of randomly sampled savanna and forest locations ($N=100$ per land cover per island) across major soil orders; and predicted differences in forest and savanna surface soil (i.e. O and A horizons) properties including (b) soil pH; (c) soil organic matter; (d) the sum of extractable bases; and (e) extractable aluminium. Predictions are based on spatially explicit linear models and error bars indicate 95% confidence intervals.

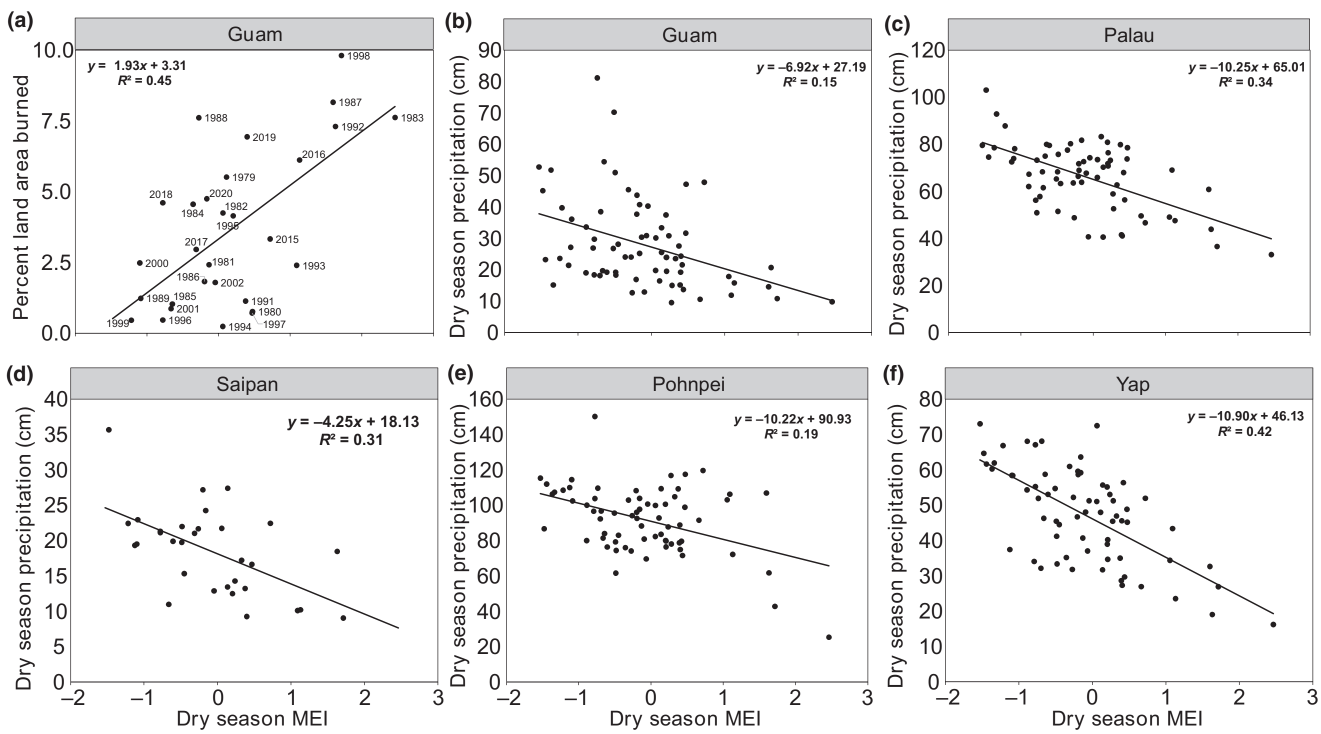

FIGURE 7 Relationships between mean dry season (January–June) Multivariate ENSO Index (MEI; where higher values indicate higher intensity El Niño events), and (a) annual percent land area burned on Guam (1979–2002; 2015–2020) and annual "dry season" (January–June) precipitation for (b) Guam (1950–2019), (c) Palau (1952–2019), (d) Saipan (1989–2019), (e) Pohnpei (1952–2019); and (f) Yap (1952–2019).

et al., 2022; Gillespie et al., 2012). While widely characterisation as 'degraded' and the focus of ecological restoration efforts (Dendy et al., 2015; Friday et al., 2021; Povak et al., 2020), many Micronesian savannas contain native plants and animals adapted to this habitat (Costion & Lorence, 2012; Merlin & Raynor, 2005) and are valued aesthetically and for medicinal plants (Balick & Kitalong, 2021; A. Singeo, pers. obs.). However, the potential invasiveness of savanna species like *M. floridulus* and the possible succession from forest to savanna to open erosion scars, or badlands, due to repeated fires certainly warrants further research (Kottermair et al., 2011; Minton, 2006; Shelton & Richmond, 2016). Fijians, for example, acknowledge that *talāsiga* savannas are anthropogenic and are poor areas for farming due to low soil fertility (Spriggs, 2001). Several paleoecological studies link *talāsiga* formation on Fiji to both anthropogenic burning and subsequent soil depletion through agricultural intensification and erosion (Hope et al., 2009; Roos et al., 2016). Similar fernlands across the Pacific, such as *toafa* in Tonga and *kula* in Samoa, are also associated with burning (Nunn, 1997; Whistler, 1992) Savanna formation also appears to have been relatively rapid (Athens et al., 1996; Spriggs, 2001), which may also indicate their distribution has been relatively stable. While low savanna soil fertility may inhibit tree establishment, insight from Madagascar and New Caledonia indicate that in addition to fire, island savannas are influenced by dispersal limitation, which restricts the ability of trees to recolonise savanna vegetation (Goel et al., 2020; Ibanez et al., 2013). Dispersal limitation due to environmental filtering is widespread across Pacific island forest tree taxa (Franklin et al., 2013) and can be exacerbated by the loss or disruption of seed disperser communities (Chimera & Drake, 2011; McConkey & Drake, 2015). Alternatively, forest expansion on Palau over the past 40 years, often along savanna edges, indicates some island landscapes may be more dynamic (Dendy, Collins, Mesubed, et al., 2022).

Low soil fertility has been proposed as a driver of Micronesian savannas (Dodson & Intoh, 1999; Hunter-Anderson, 2009) and the positive correlation between island age and savanna cover ($r = 0.58$) may indicate greater savanna extents are associated with older, more weathered soils (Figure 2d). However, research on continental savannas largely indicates that fire and climate are stronger determinants (Bond, 2010; Scholes & Archer, 1997). Our soils analyses indicate that forest and savanna occur on all major soil orders with inconsistent differences across islands (Figure 6a). For instance, savannas were more likely than forest to occur on typically weathered, low fertility Oxisols on Chuuk, Palau and Yap, but more or equally likely to occur on higher fertility Mollisols on Guam, Tinian and Rota. Forest and savanna were equally likely to occur across the most dominant soil type, Inceptisols, on the wettest islands of Pohnpei and Kosrae, which suggests some independence between soils and vegetation type at least at this coarse level. Compared to forest sites, savanna soils tended to be more acidic with lower soil organic matter (Figure 6b,c), which is consistent with *talāsiga* savannas on Fiji (Morrison, 2019). At least for Palau and Guam, savannas had substantially higher amounts of extractable aluminium (Figure 6d). The negative effects of aluminium toxicity on plant growth is well documented and restricts plants' ability to uptake available nutrients (Poschenrieder et al., 2008; Wright, 1989). Higher levels of aluminium in savanna soils is likely an outcome of the long-term weathering and erosional processes discussed above, and is a critical consideration for savanna reforestation as it limits the effectiveness of fertilisation being trialled by projects in the study region (Dendy et al., 2015; Friday et al., 2021). Our results should also be interpreted with caution as they do not reflect actual measured variability of soils across savanna and forest sites but rather the likelihood of forest and savanna sites to be distinguishable based on their distributions over areas where soil types and properties are defined by NRCS soil maps.

The high proportion of area burned within savannas as well as the high re-burn frequency indicates that fire exerts a strong influence on the persistence of savannas in Micronesia (Table 1; Figures 3 and 5b). However, it is difficult to ascertain whether fire is leading to forest loss as in New Caledonia (Ibanez et al., 2013) as the land cover products available at fine enough resolution to capture the effects of predominantly small fires (Figure 1c) are static. Fire perimeters did intersect with substantial areas of forest in some years, especially on Tinian, Yap, and Rota (Figure 5b). Despite the short fire histories, the predominance of burned extents within savannas, especially on Guam and Palau suggest most fires do not spread into forests (Figures 3 and 5b; Dendy, Mesubed, Colin, et al., 2022). This pattern is especially notable in light of the extensive forest perimeters lying adjacent to fire-prone savannas on many islands indicated by the "forest exposure" variable (Table 1; Figure 3). Closer examinations of historical events are critical to understanding land cover change locally as Dendy, Collins, Mesubed, et al. (2022) show Japanese colonial extractive industries led to a 26% decrease in forest cover on Palau between 1921 and 1947, much of which recovered in the following decades.

In general, based on the relative infrequency of fire over evolutionary timescales and the contemporary influx of weeds (Trauernicht, Pickett, et al., 2015), it is largely assumed that fire spread into Pacific Island forests leads to their contraction and replacement by fire-adapted vegetation (D'Antonio & Vitousek, 1992). Plot-level studies clearly indicate that fire can cause abrupt changes in island vegetation (Hughes et al., 1991; Newman et al., 2018; Trauernicht, Ticktin, et al., 2018), after which an alternative ecological state may be maintained through recurrent fire (Kitzberger et al., 2016; Tepley et al., 2018). However, on Madagascar, human fire use was found to be largely confined to savannas and unrelated to contemporary forest loss, mirroring much of the continental tropics (Phelps et al., 2022). One challenge posed by the LANDFIRE product is that the available vegetation categories, designed to align somewhat with US continental classes, may miss meaningful ecological differences. For instance, large expanses of forest on Tinian, Saipan, and Guam are comprised of non-native *Leuceana leucocephala* or *tangantangan*, which is not explicitly defined and may differ in flammability from native and other secondary forest types such as agroforest. Our analyses would be improved by a temporally dynamic land cover product available at spatial resolutions such as

LANDFIRE (30 m) that capture landscape complexity and the potential effects of smaller fires. While local forestry and conservation organisations lack the capacity for on-the-ground assessments of all fires, they have documented forest impacts especially during drier years (C. Camacho-Fejeran, J. Manglona, F. Ruegorong, A. Singeo, pers. obs).

The geographic scope of our study region also allows us to identify climatic constraints on human burning. More abundant, year-round rainfall intuitively equates to less fire activity (e.g. Figure 2a,f). Despite a lack of fire perimeter data for the wetter islands of Chuuk, Pohnpei and Kosrae, anecdotal evidence indicates that savannas are commonly burned on these islands (van der Brug, 1985) (J. B. Friday, C. Trauernicht pers. obs., W. Raynor pers. comm.) The limited extent of savanna on these islands suggests that despite ample ignition sources, rainfall can limit the landscape-level, ecological effects of cultural burning (Figure 3). These linkages among fire, climate and vegetation structure are fundamental to assessing current and future fire risk and impacts, especially as rainfall varies year to year (Trauernicht, 2019). Importantly, El Niño events typically lead to drought across the entire Pacific Basin (Frazier et al., 2019; Iese et al., 2021). Guam's longer record of annual area burned (1979–2002; 2015–2021) indicates fire activity correlates strongly with El Niño intensity (Figure 7a) with nearly 10% of the island having burned during the strong 1997–1998 event. The negative relationship between rainfall and El Niño intensity was well supported for Guam, Palau, Saipan, Yap and Pohnpei and also points, albeit indirectly, to the potential for elevated fire risk under strong El Niño events across the region (Figure 7). On Pohnpei, one of the wettest islands in the region (>1800 mm $year^{-1}$ mean annual rainfall; Table 1), a report estimated 25% of the island burned during the severe 1982–1983 El Niño event (van der Brug, 1985). Savannas also increase the sensitivity of landscape fire risk to rainfall due to the effects of grassland fuel accumulation. Elevated rainfall increases annual area burned in Australian savannas (Gill et al., 2000) and has a stronger effect on fire probability than short-term drought in Hawai'i (Trauernicht, 2019). Long-lead El Niño forecasting can provide time for communities to prepare for more severe fire seasons and other drought impacts (Frazier et al., 2019).

4.1 | Management implications

Conservation, forestry and fire suppression agencies are well aware of fire issues and impacts on both terrestrial and marine areas across Micronesia and have been integrating fire into planning at the watershed- to island-scale. The majority of fire mitigation work in the region is grant-funded and largely tied to protecting marine ecosystems through erosion prevention (Minton, 2006; Shelton & Richmond, 2016). The authors of this paper have contributed to or led a variety of fire management projects in the region, including prevention using place-based educational curricula, public outreach, and signage (e.g. "Real Hunters Don't Burn" in CNMI and "Smokey fruitbat" on Yap); and fuels mitigation largely through community-based reforestation projects to reduce savanna fuel continuity (Friday et al., 2021). The success of these efforts is dependent on continued funding and excluding fire from establishing reforestation projects. Fire perimeters (e.g. Figures 3 and 5b) and anecdotal observations suggest many fires extinguish at forest edges, indicating strategic and/or large-scale reforestation has potential to limit fire and protect communities and ecosystems.

The extent of fire in the region and its clear relationship with people indicate that local knowledge of burning has potential lessons for contemporary land care in Micronesia (Bubb & Williams, 2022; Dendy, Mesubed, Colin, et al., 2022; Minton, 2006; Povak et al., 2020). For example, "farm fires" were the most common cause cited by Palauans as ignition sources on Babeldaob, while "hunting and gathering fires" accounted for most of the area burned, followed by "arson fires" (Dendy, Mesubed, Colin, et al., 2022). King (2004) presents the only rigorous ethnographic treatment of burning in the Pacific in which Fijians identified many intentional applications, specific seasons, and gender-specific roles of fire use, ranging from land clearing for agriculture, hunting, pest control, and promoting wild-harvested foods (King, 2004). Fijian burning mirrors Indigenous fire use globally and ultimately helps to frame Pacific Island savannas as cultural landscapes (Trauernicht, Brook, et al., 2015). However uncontrolled fires account for large proportions of burned area, and both fire use and fire impacts are changing across the Pacific with broader structural changes to island societies and ecologies under foreign interventions, global economic integration, introduced species, and marginalisation of Indigenous lifeways (Dendy, Mesubed, Colin, et al., 2022; Hanlon, 2009; King, 2004). Examining the biophysical drivers of fire and savannas clarifies Pacific Islanders' role in shaping their landscapes, which is critical to maintain relationships with the land into the future. Our work also provides a practical and realistic set of expectations with respect to the frequency and extent of fire based on savanna distribution and rainfall patterns that can be used to assess fire risk in other tropical insular areas where data are limited.

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CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

Analyses for fire, land cover and soils, with links to online data sets and access to island-level summary data are available at https://github.com/claytrau/micronesia_fire_analyses. Rainfall and El Niño-related data sets are publicly available from the NOAA National Centers for Environmental Information: https://www.ncei.noaa.gov/.

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BIOSKETCH

The team brings together expertise in research and on-the-ground land stewardship. They have been developing both regional and local capacity for fire research and fire impact assessment and mitigation through various partnerships and collaborations such as the Pacific Fire Exchange (www.PacificFireExchange.org) and the Pacific Islands Forestry Committee (https://www.thewflc.org/about/committees/pacific-islands-forestry-committee).

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