**Supplementary Information**
**Island ecosystem responses to the Kuwae eruption and precipitation change over the last 1600 years, Efate, Vanuatu**

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Data and R scripts can be found online at https://github.com/nastrandberg/Vanuatu.git

This file contains:

Methods, figures S1, S, S3, S4, and S5 and tables S1, S2, S3, and S4.

C/N method

To obtain total organic carbon values 5% hydrochloric acid was added to samples in beakers to remove calcium carbonates. The solution was left overnight and then topped up with de-ionised water and left until the sample settled. Once the water was clear, the sample was decanted. This process was repeated three times. The remaining solution was dried overnight at 40°C. The dried samples were then homogenised in an agate pestle and mortar.

To obtain N values, the sediments were freeze dried. Both C and N samples are weighed into tin capsules and were analysed using the Isoprime precisION with an Elementar elemental analyser. BROC3 and Spirulina standards were used for C and N measurements.

Pollen and spore analysis

We added one tablet containing ~9666 or ~14285 *Lycopodium* exotic spores (batch numbers 3862 and 100320201 respectively, from Lund University) to each sample for calculating concentrations (Stockmarr, 1971). A solution of 10% HCl was used to dissolve the *Lycopodium* tablets and any carbonates. To disaggregate organic material, the samples were boiled in 10% KOH for 10 minutes. The samples were passed through two nested sieves, 125 µm and 10 µm. The fraction >10 µm was retained for further pollen analysis. The samples were boiled with 40% HF for 30 minutes to remove silicates. Acetolysis was achieved through the removal of water using glacial acetic acid ($CH_3COOH$), and then addition of a solution of 9:1 acetic acid to $H_2SO_4$. The samples were boiled in the acetolysis solution for 3 minutes and the reaction was stopped with glacial acetic acid. The slides were mounted with glycerine jelly (Moore et al., 1991).

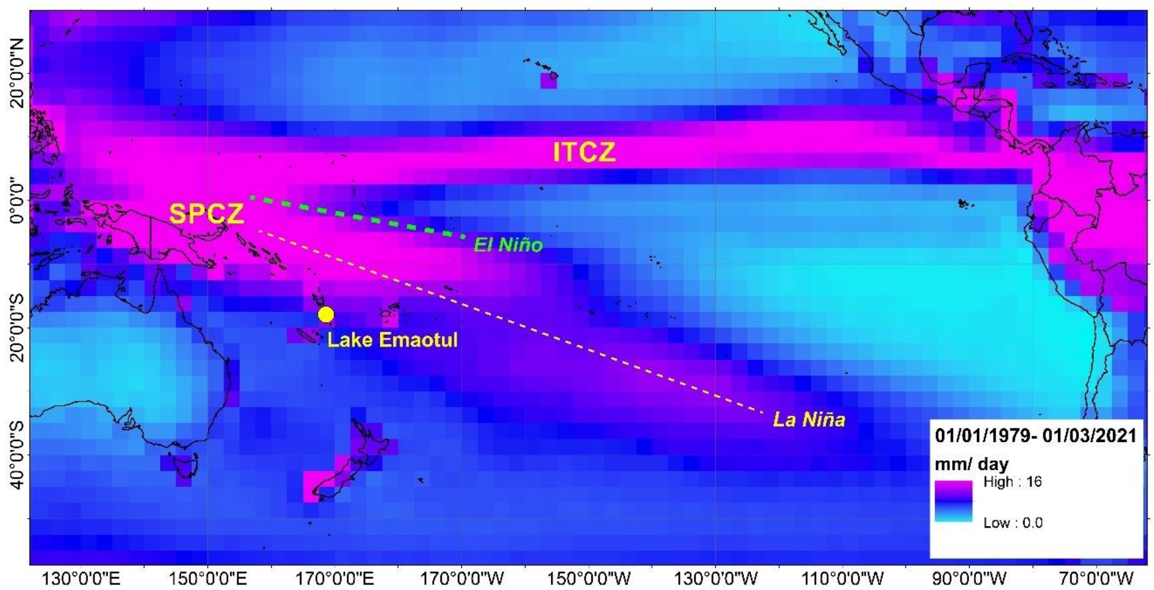



Figure S1. GPCP satellite-gauge 1979 to 2021 mean precipitation mm/day (provided by the NOAA/OAR/ESRL PSL, Boulder, Colorado, USA, from their website at https://psl.noaa.gov/) (Adler et al., 2003). The yellow dashed line indicates the extend and direction of the SPCZ in La Niña conditions and the coarse green dashed line shows the extent during El Niño conditions.

Table S1. Radiocarbon and $Pb^{210}$ dates, cc refers to the calibration curve used in Rbacon (Blaauw and Christen, 2011).

| Laboratory ID | Age (Calibrated years before 1950) | error | Depth (cm) |
|---|---|---|---|
| **surface** | -65 | 1 | 0 |
| **3474-1** | -65 | 1 | 0.25 |
| **3508-1** | -64.67 | 1 | 0.75 |
| **3537-1** | -64.49 | 1 | 1.25 |
| **3537-2** | -64.18 | 1 | 1.75 |
| **3508-2** | -63.93 | 1 | 2.25 |
| **3537-3** | -63.57 | 1 | 2.75 |
| **3537-4** | -63.07 | 1 | 3.25 |
| **3537-5** | -62.2 | 1 | 3.75 |

| | | | |
|---|---|---|---|
| **3474-2** | -61.25 | 1 | 4.25 |
| **3537-6** | -60.52 | 1 | 4.75 |
| **3537-7** | -59.71 | 1.1 | 5.25 |
| **3537-8** | -58.56 | 1.3 | 5.75 |
| **3508-3** | -57 | 1.6 | 6.25 |
| **3537-9** | -56.26 | 1.7 | 6.75 |
| **3537-10** | -55.56 | 1.9 | 7.25 |
| **3537-11** | -54.4 | 2.1 | 7.75 |
| **3474-3** | -53.5 | 2.3 | 8.25 |
| **3537-12** | -52.75 | 2.4 | 8.75 |
| **3537-13** | -51.83 | 2.6 | 9.25 |
| **3537-14** | -50.47 | 2.9 | 9.75 |
| **3508-4** | -48.32 | 3.3 | 10.5 |
| **3537-15** | -46.68 | 3.7 | 11.5 |
| **3474-4** | -45.06 | 4 | 12.5 |
| **3537-16** | -43.19 | 4.4 | 13.5 |
| **3508-5** | -40.8 | 4.8 | 14.5 |
| **3537-17** | -37.39 | 5.5 | 15.5 |
| **3474-5** | -33.86 | 6.2 | 16.5 |
| **3537-18** | -29.32 | 7.1 | 17.5 |
| **3508-6** | -25.2 | 8 | 18.5 |
| **3537-19** | -19.22 | 9.2 | 19.5 |
| **3474-6-L** | -10.33 | 10.9 | 20.5 |
| **3537-20** | 0.44 | 13.1 | 21.5 |
| **3508-7** | 11.81 | 15.4 | 22.5 |
| **3537-21** | 34.71 | 19.9 | 23.5 |
| **D-AMS 026249 (L1 28-29)** | 124 | 24 | 48.8 |

| | | | |
|---|---|---|---|
| **D-AMS 026250 (L1 58-59)** | -58 | 25 | 78.8 |
| **SUERC-67469 (L1 90-91)** | 349 | 37 | 110.8 |
| **UBA-46366 (L1A 72-73)** | 711 | 22 | 172.79 |
| **D-AMS 026251 (L2 58-59)** | 923 | 26 | 197.82 |
| **SUERC-67470 (L3 15-16)** | 1262 | 35 | 258.71 |
| **D-AMS 026252 (L3 76-77)** | 1608 | 25 | 319.71 |
| **SUERC-67471 (L3A 58-59)** | 1853 | 37 | 338.34 |

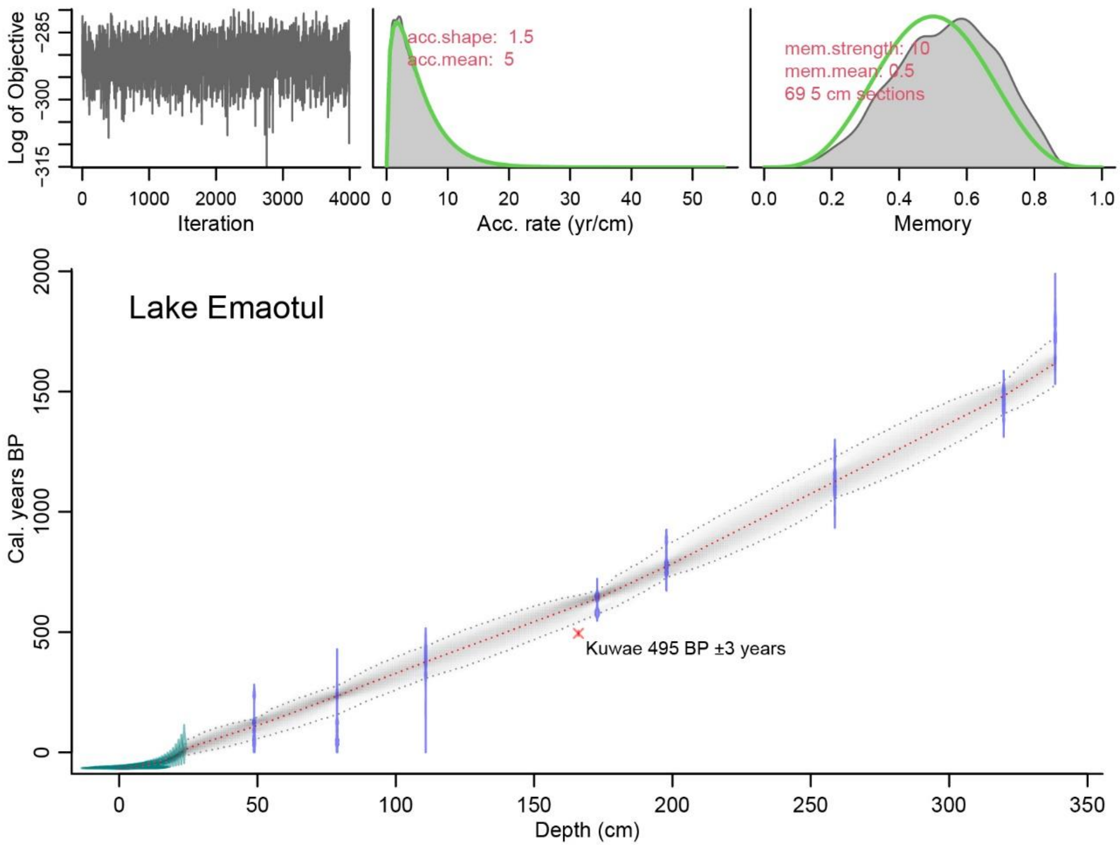



Figure S2. Bacon age-depth model for Lake Emaotul, Efate, Vanuatu calibrated using the Southern Hemisphere calibration curve (Hogg et al., 2013). (RStudio Team, 2015, Blaauw and Christen, 2011, R Core Team, 2017) after Sear et al (2020) and (Maloney et al., 2022).

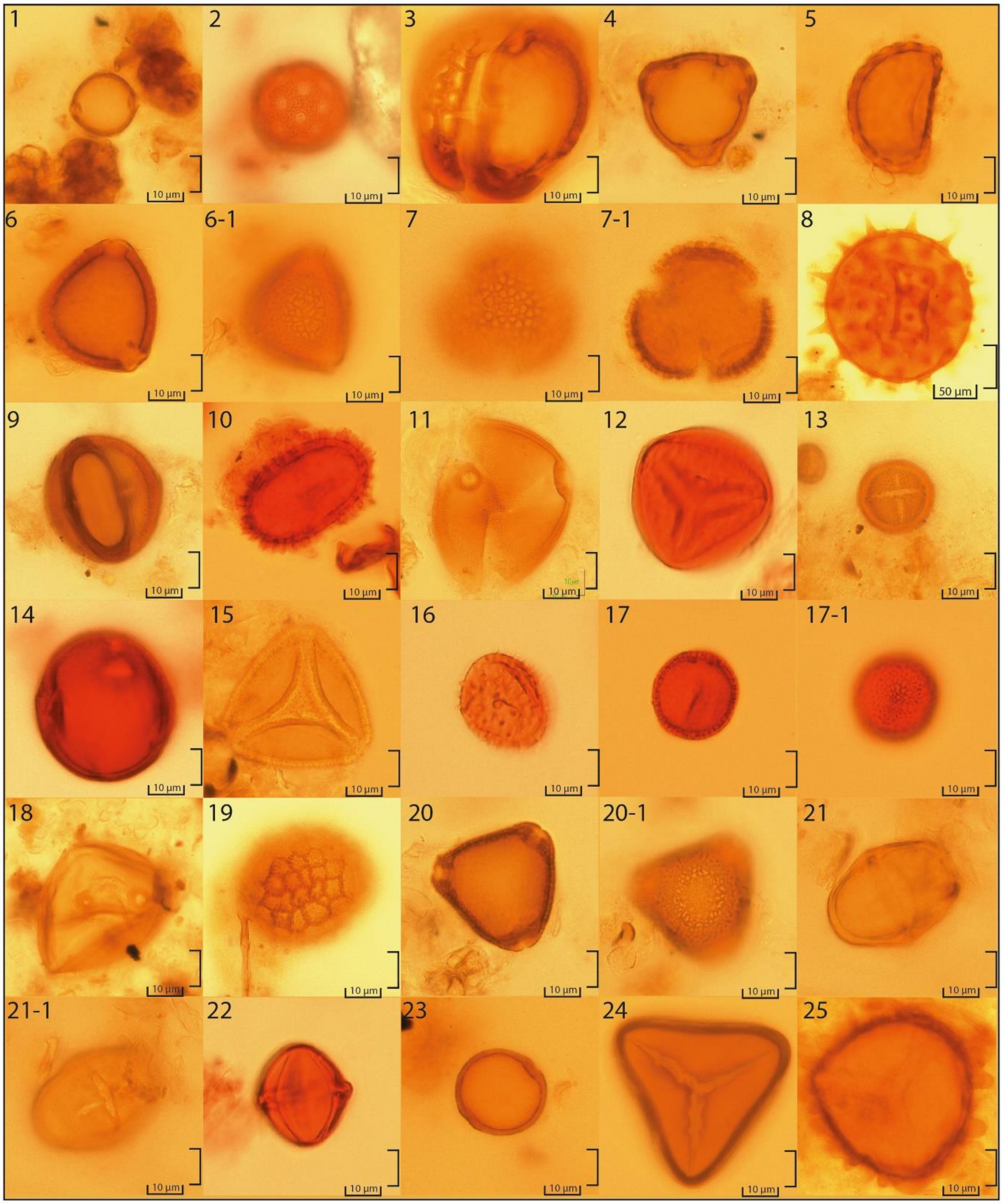



Figure S3. Key pollen and spore types. 1. *Acalypha*. 2. Amaranthaceae/ Caryophyllaceae. 3. *Barringtonia*. 4. *Casuarina*. 5. Davalliaceae. 6. *Erythrina*. 7. Euphorbiaceae/ Rubiaceae. 8. *Hibiscus tiliaceus*. 9. *Homalanthus*. 10. *Hypolepis*. 11. *Leucaena*. 12. *Lycopodiella cernua*. 13. *Macaranga*. 14. Meliaceae. 15. *Nymphoides*. 16. *Pandanus*. 17. *Phyllanthus*. 18. Poaceae. 19. Polygonaceae. 20. Sapindaceae. 21. Sapotaceae. 22. Solanaceae. 23. *Trema*. 24. Trilete gemmate spore. 25. Trilete, psilate spore

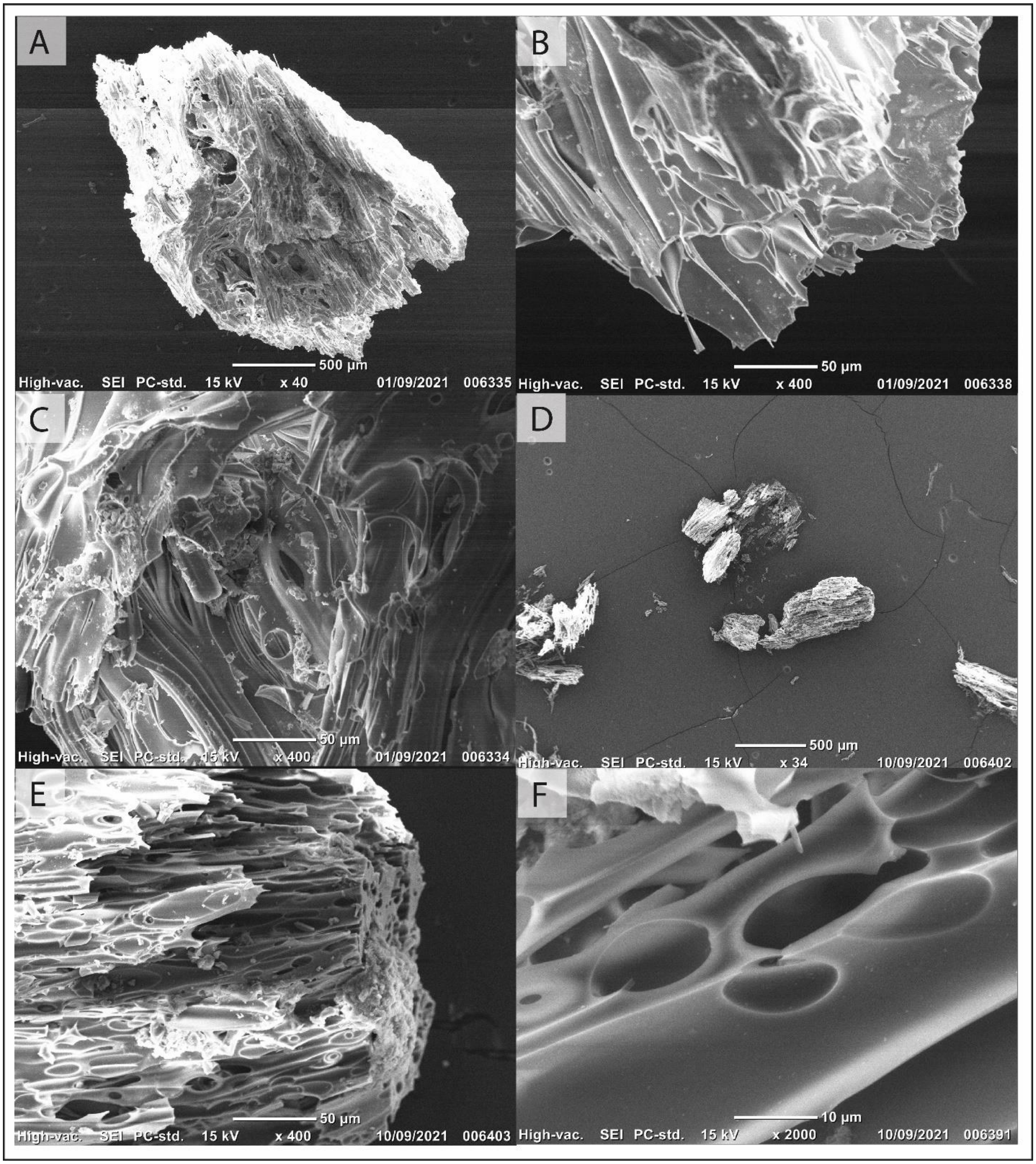
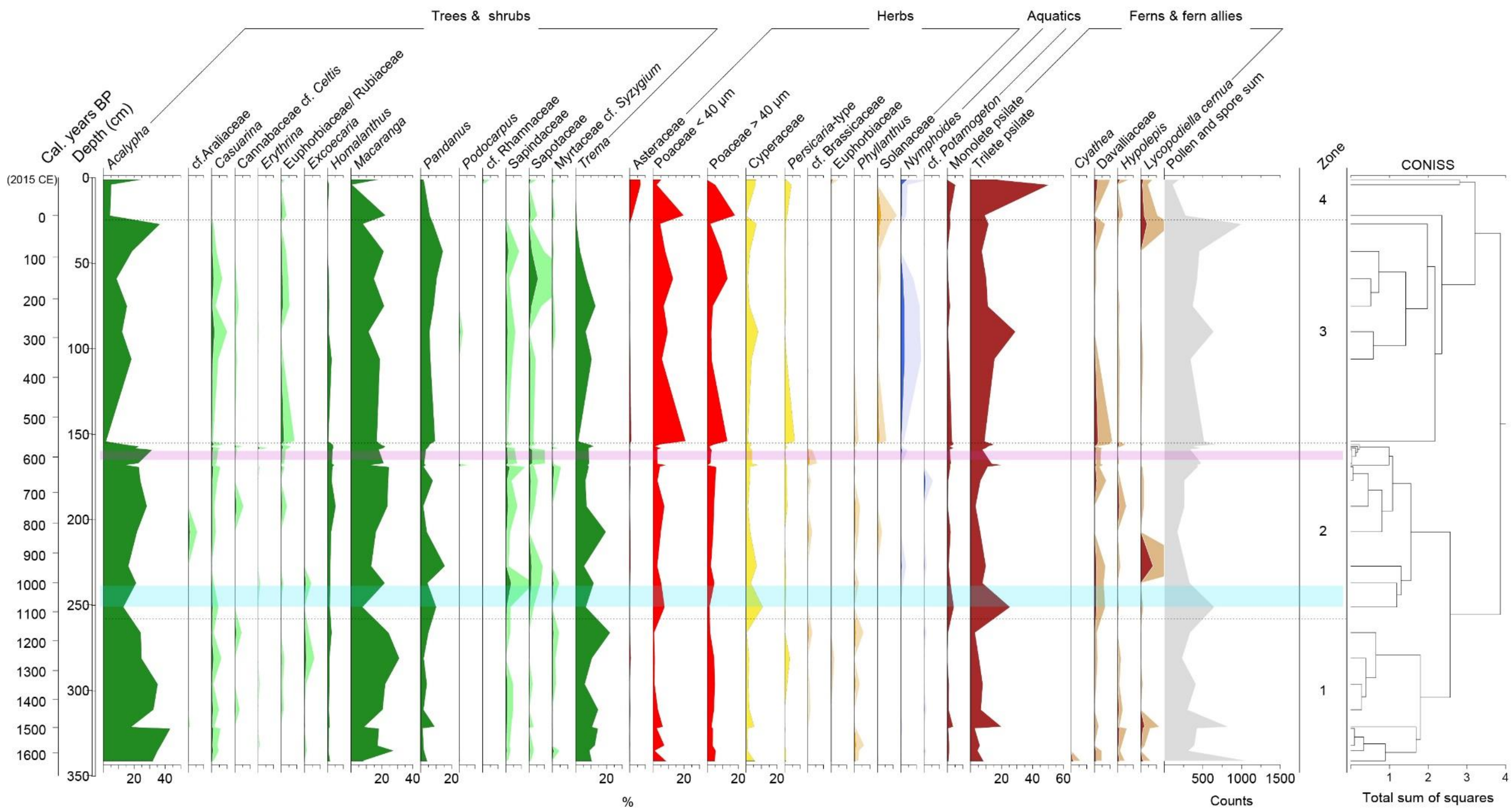



Figure S4. Scanning electron microscope images of pumice from 160–166 cm.

Table S2. Summary of the mean temporal resolution of palaeoecological methods used in this study proxies.

| Proxy | Environmental driver | Mean time resolution |
|---|---|---|
| **Chironomids** | Aquatic ecosystem | ~160 years (~33 cm) |
| **C/N** | Source of organic matter | ~10 years (~ 2cm) |
| **Itrax** | Erosion | Sub annual (0.2 mm) |
| **Tephra** | Volcanic activity?? | Discrete horizon, plus dispersed shards in some levels |
| **Pollen** | Vegetation | ~70 years (~14 cm) and ~5 years (1 cm) directly above and below the Kuwae ash |
| **Micro-and macro-charcoal** | Fire | ~70 years (~14 cm) and ~5 years (1 cm) directly above and below the Kuwae ash |



Trees & shrubs
Herbs
Aquatics
Ferns & fern allies
Cal. years BP
Depth (cm)
(2015 CE)
Acalypha
cf. Araliaceae
Casuarina
Cannabaceae cf. Celtis
Erythrina
Euphorbiaceae/ Rubiaceae
Excoecaria
Homalanthus
Macaranga
Pandanus
Podocarpus
cf. Rhamnaceae
Sapindaceae
Sapotaceae
Myrtaceae cf. Syzygium
Trema
Asteraceae
Poaceae < 40 µm
Poaceae > 40 µm
Cyperaceae
Persicaria-type
cf. Brassicaceae
Euphorbiaceae
Phyllanthus
Solanaceae
Nymphoides
cf. Potamogeton
Monolete psilate
Trilete psilate
Cyathea
Davalliaceae
Hypolepis
Lycopodiella cernua
Pollen and spore sum
Zone
CONISS
%
Counts
Total sum of squares

Figure S5. CONISS calculation of the pollen percentage diagram for Lake Emaotul showing pollen and spores which have been taxonomically identified and have >1% abundance. CONISS calculations were based on all taxa except those which are unidentified (Grimm, 1987). Taxa are grouped into trees and shrubs (green), dryland herbs (red), wetland herbs (yellow), other herbs (orange), aquatic plants (blue), and ferns and fern allies (brown). Taxa which occur in low abundances have been shown with x 5 exaggeration (pale shaded colours). The lilac shaded area represents the area where Kuwae volcanic ash was identified and the cyan shaded area represents the transition from wetter to drier climate.

Table S3. Canonical Correspondence Analysis correlation scores.

| **Environmental driver** | **Proxy** | **CCA axis-1** | **CCA axis-2** |
|---|---|---|---|
| Magnetic susceptibility | Tephra and erosion | 0.08167 | 0.7514 |
| Ti/inc | Erosion | 0.93972 | -0.1108 |
| Microcharcoal | Regional fires | 0.46558 | -0.5196 |
| Macrocharcoal | Local fires | -0.47496 | -0.5499 |
| Precipitation | Precipitation | 0.60693 | -0.1712 |

Table S4. Palaeoecological change indicated from chironomids and pollen in aquatic and terrestrial settings attributed to volcanic ash fallout in Oceania and South America.

| Continent | Country | Site | Depositional setting | Location | Site elevation (m.a.s.l) | Tephra date | Ash (or ignimbrite*) thickness (cm) | Proxy type | Response and interpretation | Recovery time (years) | Comment | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oceania** | New Zealand | Review of 18 sites from North Island (Te Ika-a-Māui) | Lacustrine and wetland | Multiple at varying distances from volcanic epicentre Lake Taupo (38°47'26.78"S 175°54'14.68" E) | Multiple | 1850 cal years BP (Tapou) | Multiple (42*-0.5) | Fossil pollen and charcoal | Proximal podocarp/ hardwood forests were destroyed by ignimbrite. *Pteridium esculentum*, Poaceae, Asteraceae and *Gonocarpus* increased. | Proximal forest ~200 $C^{14}$ years | Local climate was likely an important factor for recovery rates | Wilmshurst and McGlone (1996) |
| **Oceania** | New Zealand | Matakana | Wetland | 37°29'22.59"S 175°59'59.98" E | 1 | 665 cal. years BP (Kaharoa) | 3 | Fossil pollen | *Leucopogon fasciculatus* (shrub) and *Tupeia antarctica* (shrub) became extirpated from the area | | Anthropogenic activity may have contributed to vegetation changes | Giles et al. (1999) |
| **Oceania** | Tonga | Lotofoa Swamp | Wetland | 19°44'48.12"S 174°18'28.80" W | 3 | ~3800 cal. years BP | 50 | Fossil pollen | Vegetation change from ferns to coastal forests and then to more open conditions | >3800 | No return to pre-eruption conditions has been observed perhaps due to human arrival ~2800 years ago | Flenley et al. (1999) |
| **South America** | Ecuador | Laguna Baños | Lacustrine surrounded by páramo vegetation | 0°19'19.68"S 78°9'10.50"W | 3821 | 1500 cal. years BP (Cosanga region) | >5 | Fossil pollen | Slight increase in herbs (mostly Poaceae) | <100 | | Montoya et al. (2021), Matthews- |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | Bird et al. (2017) |
| **South America** | Ecuador | Laguna Baños | Lacustrine surrounded by páramo vegetation | 0°19'19.68"S 78°9'10.50"W | 3821 | 1500 cal. years BP (Cosanga region) | >5 | Chironomids and C/N ratio | Chironomid regime shift. C/N ratio increased. | >1500 | Montoya et al. (2021), Matthews-Bird et al. (2017) |
| **South America** | Ecuador | Laguna Baños | Lacustrine surrounded by páramo vegetation. | 0°19'10.16"S 78° 9'34.79"W | 3835 | Uncertain, potentially 1785-1786 CE<br><br>Nevado Cayamabe or Pichincha (1553 or 1660 CE) | ≥10 | Diatoms and chironomids | Chironomids showed a decrease in abundance although species composition stayed the same. | Short-lived | Michelutti et al. (2015) |
| **South America** | Ecuador | Vinillos | Wetland surrounded by glacial forests | 0°36′2.8″S, 77°50′48.8″W | 2090 | Multiple (4) between 45–42 k. cal years BP. | 18, 25, 40 and 23. | Fossil pollen, non-pollen palynomorphs and charcoal. | Slight increase in *Alnus*. Following the 40 cm tephra deposition fungal NPPs disappeared and there was an increase in *Ilex*, Melastomataceae and *Weinmannia.* Eruptions were a source of ignition. | Not estimated since recurrent disturbances occurred | Loughlin et al. (2018) |
| **South America** | Ecuador | Laguna Pindo | Lacustrine surrounded by pre-montane vegetation | 1°27'7.92"S 78°4'50.82"W | 1248 | 900 cal. years BP (Tungurahua) | >5 | Fossil pollen | Opening up of forest canopy | ~150 | Matthews-Bird et al. (2017), Montoya et al. (2021) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **South America** | Ecuador | Laguna Pindo | Lacustrine surrounded by pre-montane vegetation | 1°27'7.92"S 78°4'50.82"W | 1248 | 900 cal. years BP (Tungurahua) | >5 | Chironomids and C/N ratio | No change in chironomids, decline in C/N ratio | | Montoya et al. (2021), Matthews-Bird et al. (2017) |
| **South America** | Chile | Lake Galletué | Lacustrine | 38°40'47.6"S 71°17'30.7"W | 1150 | ~1957 CE (Llaima) | ~5 | Fossil pollen | Increase in Poaceae (grasses) perhaps due to percolation of pollen grains | | Urrutia et al. (2007) |
| **South America** | Chile | Lake Galletué | Lacustrine | 38°40'47.6"S 71°17'30.7"W | 1150 | ~ 1957 CE (Llaima) | ~5 | Chironomids | Chironomids: *Ablabesmyia* was replaced by *Parakiefferiella* interpreted as a sedimentological change | Brief change | Urrutia et al. (2007) |
| **South America** | Argentina | Lake Mascardi | Lacustrine surrounded by subantarctic forest | 41°20'0.00"S 71°33'60.00"W | 800 | Two tephra layers | ≥10 (both) | Chironomids | Decreased diversity and equitability | Short-lived | Massaferro and Corley (1998) |
| **South America** | Chile | Laguna Miranda | Lacustrine | 46° 8'40.00"S 73°26'40.00"W | 120 | Multiple (22) possibly including Mount Hudson) | Multiple (0.1–8) | Fossil pollen | Long-term increase of *Nothofagus* 4800–1200 cal. years BP. | Long-term following repeated disturbances | Haberle et al. (2000) |
| **South America** | Chile | Gran Campo-2 | Wetland | 52°48'37.0"S 72°55'46.0"W | 70 | 4254 ± 120 cal. years BP (Mount Burney) | ~8 | Fossil pollen | Decline in *Nothofagus* and initiation of primary succession. | 800 | Fesq-Martin et al. (2004) |

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