INSIGHTS INTO THE NATURAL AND CULTURAL HISTORY OF TYPHA ORIENTALIS (RAUPŌ) IN AOTEAROA NEW ZEALAND

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Highlights

1. *Typha* (raupō) is a widespread anthropogenic indicator in Aotearoa New Zealand.
2. The natural history of raupō reveals a rich biocultural significance.
3. Raupō can be invasive but also has strong potential for wetland phytoremediation.
4. New Zealand's short human era highlights properties intrinsic to *Typha* worldwide.

Abstract

A new multi-proxy paleo database for lake ecosystem and catchment change in Aotearoa New Zealand (ANZ) points to the potential resource and ecosystem service roles of *Typha orientalis* (raupō). In the context of chronic wetland degradation in Aotearoa New Zealand over the past century, this iconic yet enigmatic wetland plant can be viewed, alternately, as an invasive threat; a valuable cultural and economic resource; and a natural, indigenous agent for bioremediation. Our investigation reconstructs the history of *raupō* over the past ~1000 years, based on 92 new pollen records generated from lake sites across ANZ. At almost every site where raupō is present today, its expansion is promoted to varying extents during periods of human activity and at 87% of sites investigated, raupō shows its maximum palynological abundance post human arrival. Multiple patterns of response over time point to a range of hydrological, trophic, and cultural scenarios that are conducive for raupō expansion, raising prospects for its potential role in mitigating the ecological impacts of disturbance. Raupō expansion, promoted by anthropogenic forest clearances and associated sediment and nutrient flux, would in turn have provided new opportunities for its use as a valuable food and material resource, prompting further questions as to the extent it was deliberately managed by indigenous populations. As both a benefactor from, and provider for, expanding populations, raupō may be regarded as a human associate in ANZ prehistory. As well as being indigenous to ANZ, *T. orientalis* also occurs naturally in Australia and east Asia and shares the intrinsic ecological and morphological attributes of the ~40 species or hybrids of *Typha* that span most of the planet. This work therefore may encourage wider application of the genus as a biocultural asset informed from its local natural history.

KEYWORDS: Spatio-temporal distribution, wetland restoration, paleoecology, bioremediation, ethnobotany,

Graphical abstract/striking image (insert here)

1. Introduction

Typha, the only genus in the 'cattail' family, Typhaceae, comprises nearly 40 species and hybrids. All are emergent rhizomatous macrophytes, common and characteristic in wetlands throughout the world (Fig. 1). These plants are typically culturally iconic as well as ecologically distinctive and have provided a rich source of food and materials for indigenous peoples, in some regions persisting through to the present day [1]. In recent decades, *Typha* (the term is derived from the Greek word for marsh) has been expanding across many wetlands and lake margins, earning it the reputation of being an invasive species in some regions [2, 3]. At the same time, field and experimental observations are revealing wide-ranging benefits of *Typha*, particularly for bioremediation programmes aiming to restore degraded wetlands [4, 5]. As these various attributes are broadly applicable across the genus, there is widespread interest in improving understanding of the ecology and natural history of *Typha* and its connections with indigenous cultures around the world. Beyond observations from recent decades, there is limited information about the longer history of *Typha* and, in particular, its role in and responses to human-environment interaction and expansion of agriculture. An exception is a study from North America [3], using pollen and herbarium data to show *Typha* increasing at many sites over the past 1000 years, linked to human activities.

Fig. 1. Global distribution of *Typha* spp. Source: Angiosperm Phylogeny Website https://www.mobot.org/MOBOT/research/APweb/welcome.html

In Aotearoa New Zealand, *Typha* is represented by a single, indigenous species, *Typha orientalis*, locally known as raupō and we use this term hereafter to distinguish the New Zealand species. Raupō is common in coastal and lowland fertile wetlands; on the margins of ponds, lakes, slow flowing streams, and rivers, in North and South Islands; and on Raoul Island (Kemadec Islands group) (https://www.nzpcn.org.nz/flora/species/typha-orientalis/) (Fig. 2). It was also introduced into the Chatham Islands by Māori [6, 7] where it is described as 'scarcely established' [8]. Raupō is found less frequently on the margins of low moor bogs and occasionally in muddy ground within industrial areas. Although indigenous to Aotearoa

New Zealand, raupō is also endemic in Australia, Malaysia, Indonesia, and the wider western Pacific.

Fig. 2. Aotearoa New Zealand showing location of sites mentioned in text (inset) and location of the lake sites investigated in this study.

As with *Typha* in many other regions, raupō populations have expanded at many sites as a consequence of nutrient and light increases associated with pastoral agricultural expansion during the European era [9]. Conversely, populations have also declined in expanse due to widespread and persistent drainage operations resulting in the loss of about 90% of wetlands in Aotearoa New Zealand over the past 150 years [10]. Little is known about its longer-term history and in particular its response to human settlement and changing landuse patterns.

Compared with most regions where human interaction with *Typha* may have evolved over millennia, the relatively short, concise human era in Aotearoa New Zealand presents a distinctive opportunity to investigate unequivocally the natural history of *Typha* before and after the arrival of people. This paper aims to provide improved understanding of the ecological response of *Typha* in these two distinctive phases, and to contrast modern observations in the context of an intensified agricultural regime with *Typha*'s response to pre-colonial indigenous activities. We begin by briefly reviewing previously published Aotearoa New Zealand Holocene pollen records before examining a suite of new records spanning the last ~1000 years to trace in greater detail the history of raupō in relation to human-environment interaction. These new pollen records have been developed under a wider research programme, 'Our lakes' health: past, present, future' (hereafter 'Lakes380') that is investigating the history of lakes in Aotearoa New Zealand (www.lakes380.com). This research programme is not only generating an extensive archive of raupō pollen records (Fig. 2) but is also providing a wealth of information about the wider local and regional environmental context to the longer-term history of raupō. Whilst the scope of the current paper is to reconstruct the history of raupō across Aotearoa New Zealand from pre-settlement to present day, it will also provide the basis for subsequent investigations that will use this wider dataset to develop a better understanding of the role raupō plays in the wetlands and lakes of Aotearoa New Zealand. We hypothesise that raupō pollen records will reveal a consistent anthropogenic response, increasing in abundance in the presence of human activity and possibly extending its geographic range.

The next section explains the rationale for this hypothesis by considering how the biology, ecology, and morphological traits of *Typha* species worldwide have favoured their capacity to expand in disturbed wetlands as well as promoting their importance both in prehistory and today.

2. Context

2.1. *Typha* biology, ecology, and morphology

The increasing distribution and abundance of *Typha* in wetland ecosystems around the world, particularly in North America, in recent decades is primarily attributed to anthropogenic-related disturbances to wetland hydrology and nutrient loads [11]. *Typha* is biologically and physiologically well-suited to take advantage of these disturbances. *Typha* produces an abundance of small, light (<100 µg), wind-dispersed seeds promoting colonisation of, and between, wetlands across great distances. The seeds germinate readily, within a few days, but require a high light intensity for growth [12]. Ungerminated seeds may also remain viable in the wetland substrate for lengthy periods and form a persistent seed bank and source for expansion should suitable growth conditions develop.

Following seedling establishment, *Typha* develops axillary rhizomes with roots that anchor plants into wetland sediments. Rhizome tips develop into elongated linear leaves that grow rapidly and the plants develop a comparatively large stature which together with aggressive clonal propagation can result in dense monotypic stands [13-16]. A highly efficient root-aeration system adds to *Typha’s* competitive edge over other species, especially in organic-rich, flooded soils [17] and the plants can survive as floating mats which then opportunistically colonise newly disturbed sites. *Typha* rhizomes also store carbohydrates as the leaves grow and this serves to maintain the plant over its dormant winter period and to supply rapid new growth in spring. The dense mat of rhizomes retains debris resulting in a shallowing of the waterbody, enabling further rhizome propagation.

These biological attributes equip *Typha* to respond rapidly and aggressively to changing environmental conditions. Observations in North America, for example, report near pure *Typha* stands colonising an area of 40–80 m^2 within months to a few years [18, 19]. Disruption of natural hydrologic regimes and increased nutrient inputs into wetlands from agricultural runoff are repeatedly identified as underlying drivers of *Typha* invasion. Pollen studies have also shown that substantial increases in local abundances of *Typha* can rapidly follow landuse changes resulting in increased sediment and nutrient influxes to estuarine habitats [20]. *Typha* is also flood-tolerant and generally favoured by moderate flooding [21, 22]. Under naturally varying conditions, however, seasonal and inter-annual variability in water depths tends to keep *Typha* under control [2]. Conversely, a lack of variability, such as when water levels are controlled or artificially lowered, can reduce these seasonal extremes allowing the spread of *Typha* [23, 24]. In other situations, *Typha* spread can be enhanced by hydrologic alterations that raise the water table and create wetter soil conditions. In summary, *Typha* expansion into natural and controlled wetlands is often associated with a range of hydrologic alteration scenarios.

Sediment and water chemistry are also important factors in *Typha* growth and survival. *Typha* is often outcompeted by other aquatic macrophytes in low-nutrient, oligotrophic conditions [25, 26] but gains advantage under more eutrophic conditions. Increased nitrogen (N) and phosphorus (P) concentrations in wetland waters promote the growth of *Typha*, enabling its aggressive proliferation [25, 27, 28]. *Typha* invasion often follows increased sediment deposition in wetlands, due to enhanced inputs of sediment-attached N and P. *Typha* can also tolerate soils contaminated with heavy metals better than many of its competitors [5, 29, 30].

2.2. Benefits of *Typha*

2.2.1. Typha as a traditional source of food and materials

Wherever *Typha* species occur in the world, they have been put to economic use by traditional societies [1], principally as sources of food and material serving a wide variety of functions. Although most of these observations relate to modern practice, in many cases they relate to long-established tradition practised within a particular culture and location across many generations, often extending into prehistoric times (Table 1). For example, *Typha* starch grains have been identified on the surface of a stone from the Paleolithic campsite of Bilancino (Florence, Italy), dated to around 25 000 bp, signifying that these and other local plants may have been used to grind into flour – presumably to make some kind of bread – by these ancient peoples long before the local 'agricultural revolution' [31]. In Aotearoa New Zealand, early European observations demonstrate that Māori use of raupō must also have prehistoric origins.

Table 1. Traditional economic usage of *Typha* species around the world

Part of plant	Traditional Use	Region	Source
Leaves, stems	Sandals, footwear	Peru	Yacovleff and Herrero, 1934 [32]
	Spears, spear handles	Australia	Bailey, 1902 [33]
	Rope, string	Philippines	Brown, 1951 [34]
	Rope, string poi[1]	Australia Aotearoa New Zealand	Gott, 1999 [35] Landcare Research, 2021 [36]
	Mats, sieves	India	Watt, 1908 [37]
	Wickerwork, baskets	Java	Heyne, 1950 [38]
	Roofing thatch for huts, Houseboats Houses (whare)	India Aotearoa New Zealand	Watt, 1908 [37] Harman, 2014 [39]
	Watercraft	Tasmania Aotearoa New Zealand	Gott, 1999 [35] Te Rūnanga o Ngāi Tahu Collection, 2017 [40]; Barnicoat, 1844 [41].
	Swimming floats	India	Drury, 1873 [42]
	Wicker boats	India, Pakistan	Dastur, 1951 [43]
	Sailboats rafts	Americas,	Heiser, 1974 [44] Yacovleff and Herrero, 1934 [32] Winchester, 1974 [45]
	Hats, gloves	North America	Porcher, 2020 [46]
	Foundations for island settlements in swamps	Peru	Armillas, 1971 [47]
	Dwellings (raupō whare)	Aotearoa New Zealand	Williams, 1896 [48]
Seeds floss	Cushion/pillow stuffing	Guatemala Indonesia Cuba Surinam British Honduras Peru Australia	Aguilar Girón, 1966 [49] Heyne, 1950 [38] Leon, 1946 [50] Pulle, 1938 [51]; Stahel, 1942 [52] Standley and Record, 1936 [53]

			Yacovleff and Herrero, 1934 [32] Gott, 1999 [35].
	cradle & quilt padding	Not stated	Wittrock, 1945 [54]
	diapirs	North America	Johnston, 1970 [55]
Rhizomes, roots	Food	Australia Aotearoa New Zealand many other regions	Gott, 1999 [35] Crowe, 2004 [56] Morton, 1975 [1]
Flower stalks, shoots, young leaves	Food	Australia Aotearoa New Zealand	Beveridge, 1884, 1889 [57, 58] Crowe, 2004 [56] Te Rūnaka o Ōtākou, in: Šunde , 2022 [59]
Pollen	Food (e.g. cakes)	Aotearoa New Zealand India North America Kuwait	Crowe, 2004 [56] Simmonds, 1854 [60]; Watt, 1908 [37] Yanowsky, 1936 [61] Prendergast et al, 2000 [62] Ngā Puna Rau o Rangitīkei, in: Šunde, 2022 [63]

[1] A light ball on a string which is swung rhythmically to accompany singing

Most reported usages are of leaves and stems for making a variety of items ranging from footwear to huts and even houseboats (Table 1). In Aotearoa New Zealand, traditional lightweight boats for inland water transport were constructed from raupō stems (Fig. 3). These craft, referred to as mōhiki (also, ‘mogi’), are especially common in the Waitaki and Clutha River regions (southern South Island; Fig. 2) where wānanga (workshops) are still held to teach this customary practice to younger generations [40, 41]. In some regions, entire dwellings, known as raupō whare (houses) were constructed from stems and leaves [39, 64].

Fig. 3. A mōhiki constructed from raupō stems, Kurow museum (Aotearoa New Zealand).

Photo: Rewi Newnham

The soft floss or down from ripe *Typha* seeds, which are produced in abundance, have been employed in many regions as stuffing for cushions or pillows, as padding in cradles and quilts, and even for infant’s diapers (Table 1). In Australia, there are numerous observations from the early European era of *Typha* floss used for stuffing, particularly along the Murray River where it was sold under the name ‘Murray Down’ [35].

Typha species have also been used worldwide as food [1]. Most prominent is the use of rhizomes and roots as a source of carbohydrates. Of particular relevance are the traditions practised by aboriginal Australians using the same species as in Aotearoa New Zealand (*T. orientalis*). Gott (1999) [35] reviews this widespread practice, which involved cooking the peeled rhizomes or roots either by steaming in an earth oven or roasting in fire ashes. Besides the rhizome, bases of mature shoots and leaves, the young shoots that appear in the spring and the raw young flower stalks are also eaten [57, 58, 65; all cited in 35].

In Aotearoa New Zealand, Crowe (2004) [56] reported that Māori also traditionally ate the peeled roots and the young shoots of raupō. More distinctive however was traditional Māori practice of making 'cakes' based on the copious raupō pollen. In 1880, the Reverend William Colenso gave an account of:

> "*…the pungapunga, the yellow pollen of the raupō flowers--the common bulrush… This was collected in the summer season, when the plant is in full flower, in the wet swamps and sides of lagoons, streams and lakes. I have been astonished at the large quantities of pollen then obtained. On one occasion, more than thirty years ago, I had several buckets full brought [to] me by the present chief, in his canoe, some of which I sent both raw and cooked to Kew Museum*" (Bagnall and Petersen 1948, cited in Prendergast et al., 2000 [62]). These varying uses of raupō as food sources, while less prominent today, are still well documented and highlighted in many regional oral history accounts (e.g., T. Cassidy, personal communication, in: Šunde, 2022 [59]; N. Lomax and M. Heeney, personal communication, in: Šunde, 2022 [63]).

Similar usage of *Typha* pollen is reported from several other regions across the Northern Hemisphere (Table 1). Even today, *Typha* pollen sourced from the marshes situated at the confluences of the Tigris and Euphrates rivers is widely sold in the souks and cooperatives of Kuwait, having been mixed with sugar and steamed in a bag [62].

In summary, Māori have used raupō extensively as a food and material resource, in common with customary traditional practice throughout the temperate and tropical world. Its wide-ranging value as a resource raises questions as to the extent to which raupō was deliberately managed by pre-European Māori communities, including translocation by migrating tribes, and the extent of indigenous inter-generational knowledge and understanding acquired through these practices.

2.2.2. Typha and bioremediation

The widescale loss and deterioration of wetlands in recent decades has generated interest in ecological approaches to restoration that use the natural 'ecosystem services' of indigenous species. These bioremediation or, when using plants, phytoremediation approaches require a thorough understanding of the biological and morphological traits of a particular species as well as knowledge of how they have responded to environmental change in the past. As outlined below, the ability of *Typha* to tolerate highly disturbed, nutrient rich and contaminated situations, typically at low-lying drainage foci for catchments, has promoted its potential use in bioremediation and wetland restoration approaches.

Some of these approaches have a long history, linked presumably to ancient practices. For example, Egyptians plant *Typha angustata* along the Nile to reduce soil salinity, whilst in India *Typha elephantina* is planted to prevent erosion [1]. Many studies and reviews have indicated that various species of *Typha* are able to bioaccumulate metals in wastewaters, including cadmium, chromium, iron, mercury, nickel, lead, and zinc [5, 66-69]. This decontamination role is due in large part to their rapid growth rates, capacity for elemental uptake and tolerance of contaminated environments, but *Typha* also has capacity for limiting the translocation of harmful elements from roots to above ground biomass [4, 5, 70]. Numerous other studies have shown that *Typha* can help promote water retention and reduce flood risk in managed wetlands and there is also a growing interest in using its biomass as a biofuel crop [71-78].

An example of the potentially wide-ranging restoration potential of *Typha* has been reported from the Lake Winnipeg watershed in Manitoba, Canada. There, managed *Typha* wetlands used for water retention provided additional benefits to flood water storage, including reduced nutrient loading, enhanced wildlife habitat and biodiversity, and sustainable biomass for renewable energy and bioproducts [78, 79].

In Western Europe, experiments are ongoing in using *Typha* spp. for paludification, the cultivation of rewetted peatlands. Due to its distinctive ecological traits outlined in

2.1, *Typha* has strong potential both as a resource crop and as a viable climate change mitigation option that reduces greenhouse gas emissions and hence global warming potential (GWP), with these two benefits in combination providing novel agricultural business options. Paludiculture crops thrive under waterlogged conditions that stimulate nitrogen (N) and phosphorus (P) removal from soil and water and reverse drainage-induced carbon (C) losses to the atmosphere [80]. Nutrient uptake by paludicrops can also prevent mobilisation after rewetting and promotes the purification of nutrient-rich water. In the Netherlands for example, where there is growing interest in the use of *Typha* as a paludicrop to provide a component for insulation panel material, a recent study estimated that implementing *Typha* paludiculture leads to a global warming potential reduction of ~32%(16.4tCO_2-eqha−1) [81]. These findings are consistent with an earlier study showing that *T. latifolia* as a paludicrop effectively removes various forms of N and P when harvested, and strongly mitigates CH_4 emission after the rewetting of agricultural peat soils [80].

In summary there is now an abundance of field observations and experimental work from around the world that demonstrates how and why *Typha* can aggressively colonise and spread across disturbed wetlands whilst at the same time offering strong potential for bioremediation and wetland restoration efforts. The species found in Aotearoa New Zealand shares the same biological and physical traits that support this behaviour and although we are not aware of any experimental investigations involving raupō, its expansion in wetlands in Aotearoa New Zealand in recent decades typically coincides with alteration of hydrologic and nutrient regimes, consistent with these international studies involving other species.

2.3 Previous Holocene records of raupō in Aotearoa New Zealand

Not surprisingly, published work from Aotearoa New Zealand fossil records shows patchy, discontinuous raupō presence in both space and time. Nevertheless, some interesting patterns stand out. First, consistent with its modern distribution, raupō is mostly absent from pollen records at sites above the lowland-montane zone (typically >800 m a.s.l) and tends to be more prominent at northern sites than in the south (Fig. 3 and 4). For example, raupō pollen is present in late Holocene (the past several thousand years) sediments at Lake Coleridge, Canterbury (Fig. 2; 510 m a.s.l) [82] but not recorded at all in three Holocene pollen and macrofossil records from the nearby Prospect Hill region (Fig. 2) in the same catchment at 740-800 m asl [83].

Also consistent with modern observations, the raupō paleoecological record points to an opportunistic response to natural disturbance. In particular, where volcanic deposits are recorded at lower elevation pollen sites, raupō pollen often appears or increases prominently in the immediate overlying assemblages [9, 84-89]. Moreover, the plant's affinity for nutrient-rich sites is apparent. Raupō pollen is rare from lowland acidic low nutrient *Sphagnum* [90] or restiaid peat bogs [91, 92] but can be prominent where nutrient levels are higher [9]. At a few sites, raupō pollen levels increase during phases of lake level lowering or hydroseral succession indicated by stratigraphic change [9].

All of the characteristics noted above are observed in Holocene pollen records from Lake Poukawa, eastern North Island (Fig. 2), a lowland (20 m a.s.l) shallow lake surrounded by extensive peat swamps that contained abundant raupō prior to drainage for pastoral agriculture in recent decades [87]. Pollen assemblages from drill sites taken beyond the current lake perimeter indicate raupō prominence during an earlier undated warm period, assumed to be the last interglacial (~125,000 years ago), and absence from sediments dated to the subsequent (last) glacial phase when presumably colder climates prevented its survival in this region. In contrast, Holocene lake sediments show highly variable raupō pollen percentages with peak levels during fen swamp phases reflecting lake level changes and immediately following tephra layers.

A final pattern, evident at some sites and consistent with modern observations, is that raupō often becomes more prominent in the anthropogenic era [89, 93-97]. This observation is not universal. For example, Wilmshurst (1997) [98] presents pollen diagrams from two lowland eastern North Island sites that show no obvious raupō increase in the anthropogenic era, with continuous low pollen percentages being slightly higher overall in pre-anthropogenic era sediments at both sites. Caution is required in this interpretation. Whilst McGlone's (2009) [9] review of wetlands in Aotearoa New Zealand notes that raupō pollen is well represented and often completely dominates pollen sums, previous work, consistent with *Typha* pollen observations from North America [99], suggests it may not be well-dispersed beyond the lake margins where the plant grows [87, 100, 101]. Both lakes investigated by

Wilmshurst (1997) [98] are comparatively deep and large enough in area for the pollen cores at the lakes' depocentre to be insensitive to raupō variability in the littoral margins.

These observations from Holocene records point to overall raupō behaviour that is broadly consistent with modern ecological observations, but they are drawn from a relatively small number of records. The Lakes380 programme offers the opportunity to build upon these previous observations with a more targeted investigation of the natural and anthropogenic history of raupō.

3. Material and Methods

3.1. Study lakes and sediment coring

The research programme Lakes380 (www.lakes380.com) aims to enrich understanding of the environmental, social, and cultural histories of lakes in Aotearoa New Zealand. These lakes cover a 12-degree latitudinal gradient and a range of environmental gradients including altitude, size, depth, trophic status, and geomorphic-catchment characteristics from coastal to alpine locations. Sediment cores from a total of 92 lake sites were analysed as part of this raupō study (Supplementary Table S1).

At each lake, four sediment cores were taken in close proximity at the deepest part of the lake using a UWITEC Gravity corer (Mondsee, Austria) fitted with two metre polyvinyl chloride (PVC; 90-mm dia.) core barrels. Upon extraction, core barrels were packed with florist foam to prevent sediment movement, and after settling, the barrels were cut into one metre lengths for transportation. Cores were kept refrigerated while in the field and in transit to the laboratory at GNS Science (National Isotope Centre, Lower Hutt, Aotearoa New Zealand), where the cores were split along the longitudinal plane, described, and imaged.

3.2. Palynology

Pollen was extracted from 0.25 cm^3 sediment at a variable sampling interval of 1–2 and 3–4 cm in the upper 65 cm of the cores and up to 10 cm intervals for the lower section (>65 cm) of most cores. The variable sampling interval was employed to build a vegetation reconstruction with a focus on the boundaries of vegetation change that have occurred at these lake sites over the past ~1000 years with respect to pre- and post-human vegetation and landscape change. Pollen extraction was carried out following standard laboratory techniques [102], but methods were refined to streamline pollen processing based on the sedimentary characteristics of each lake with the goal to achieve good pollen recovery with minimum processing steps. Samples were prepared using 10% hot HCl, acetolysis, and 6 µm sieving. A density flotation was applied for strongly minerogenic sediments. Exotic Lycopodium tablets were added to each sample to allow the calculation of pollen concentrations. Pollen and spore identifications were made using standard texts [103-107] and Aotearoa New Zealand pollen reference collections at GNS Science. Pollen taxonomy follows Moar et al. (2011) [108].

Pollen data are presented in the form of relative frequency of a minimum pollen sum of 150 grains. This sum includes pollen from all dryland plants, i.e. trees, shrubs and herbaceous plants, non-native plant taxa and the bracken fern *Pteridium esculentum*. *P. esculentum* is included in the dryland pollen sum as its growth form in a (post) disturbance landscape is closer in functional morphology to a shrub than a fern, and communities are ecologically equivalent to shrubland [109]. Pollen of other groups (wetland, aquatics, ferns, tree ferns as well as non-palynomorphs) were excluded from the pollen sum, but their percentages were calculated as a proportion of dryland pollen plus the respective group. It should be noted that interpreting relative frequency data at face value is problematic because of the compositional effect, but is preferable here to the use of alternative metrics such as pollen concentration or influx that are biased by site-specific, large and as yet unconstrained variations in sediment accumulation rates over the last 1 ka.

Charcoal was counted as number of fragments on the pollen slides and presented as concentration per cm^3.

3.3. Principal component analysis

The primary objective of principal component analysis (PCA) in this study was to determine the stratigraphic relationships between raupō and other pollen taxa of interest, in particular in relation to the research hypothesis. PCA was applied to square-root transformed pollen percentages, scaled to unit variance. Only plant taxa that occur in at least 20 of the 92 sites (22%) and have a maximum abundance in the dataset of at least 2% were included. A list of included taxa can be found in the Supplementary Fig. S1 and Supplementary Table S2. PCA was performed in R v.4.1.0 [110] using package vegan [111]. Plots were created with package ggplot2 [112].

3.4. Chronology

Although radiometric dating has been undertaken for some of these records, this research primarily draws upon a well-established chronostratigraphic framework for the past millennium in Aotearoa New Zealand based on changes in dryland pollen [109, 113]. Throughout Aotearoa New Zealand, pollen records for this interval typically show no obvious evidence for human activity until ca. 1250 AD, consistent with material archaeological records [114]. From ca. 1250 AD, key indicators for early Māori activity, often referred to as the Polynesian era, are a marked rise of charcoal accompanying the sustained decline in tall tree pollen and an accompanying increase in disturbance indicators, typically *Pteridium esculentum*. As we cannot preclude non-visible human presence in the pollen records prior to these visible key indications of anthropogenic activity, we use the term Evidence for Māori Settlement (EMS) for this period. Prior to this period, we use the term pre-EMS, essentially a phase of natural variability. Finally, the European era (EE), commencing in the early 19th century, is determined in our pollen records from the appearance of introduced plants typically associated with European settlement and agriculture such as *Pinus* and *Rumex*, and increased levels of Poaceae pollen reflecting pasture grasses.

4. Results

4.1. Raupō distribution

From a total of 92 new pollen records, 32 records (35%) either have no observed raupō pollen (21 records; 23%) or trace amounts (<1%; 11 records; 12%) and most of these are typically located at higher elevations (>800 m asl) or in the far south of the South Island (Fig. 4). Of the remaining 60 records, 46 records are ‘complete’ in that they span all three phases from pre-EMS to EE and the remaining 14 records sample only the EMS and EE phases (Table 2). The 46 complete pollen records fall into three broad categories, depending upon the timing and stratigraphic pattern of raupō response. In addition, some of the 14 ‘incomplete’ records show similar characteristic stratigraphic patterns despite not encompassing the pre-EMS phase. (Supplementary Table S1).

Category I (pre-EMS) is determined as those records where the first occurrence of raupō is detected during the pre-EMS phase, as seen in a small number of sites (13; 22%), either at low amounts (raupō % <5; 10; 17%) or at a maximum (raupō % ~17-40; 3; 5%). At Lake Kereta, Kaipara Peninsula, Northland (Fig. 5a), for example, the classic EMS indicators occur after a prominent peak in raupō along with sedges (Cyperaceae). Raupō and sedges then decline to background levels before both rise again, coincident with sustained increases in bracken, charcoal, and other indicators of the EMS era.

Fig. 4. Reduced 2-taxa pollen diagrams showing raupō pollen and *Pteridium* spore percentages from lakes throughout Aotearoa New Zealand (a) Te Ika-a-Māui / North Island (b) Te Waipounamu / South Island. Inset: Chatham Islands. For each plot, Y axis is depth from lake surface in 50 cm increments and X axis increments are 25% for raupō and 50% for *Pteridium*. Blue triangles indicate earliest point after which sustained palynological evidence for human settlement occurred based on multiple palynological indicators including *Pteridium* (beginning of EMS). Green dots (and their aggregated clusters) represent archaeological sites based on https://nzarchaeology.org/archsite. A strong, albeit variable, stratigraphic association is illustrated between raupō and *Pteridium* – and hence with human settlement patterns – throughout both main islands, within its presumed natural limits.

Table 2.

Summary of raupō distribution in 92 pollen records from lakes in Aotearoa New Zealand (see Figure 1). EE = European era; EMS = Evidence for Māori settlement.

Raupō	**Record** No. (%)	**Phase** EE, EMS, Pre-EMS	**Category** (% of sites with raupō > 1%)			
			Category III (EE)	Category II (EMS)	Catgory I (Pre-EMS)	Unclassified
Present (>1%)	60 (65%)	EE - Pre-EMS 46 (50%) EE - EMS 14 (15%)	7 (12%)	35 (58%)	13 (22%)	5 (8%)
			raupō max% after EMS (87%)		raupō max% before EMS (5%)	
Trace (<1%)	11 (12%)	NA				
Absent	21 (23%)	NA				

Category II (EMS) consists of the records where raupō is present and shows a clear pattern of response during the EMS era (35; 58%). The precise timing and extent of response varies between sites. For example, at Lake Kohangapiripiri, near Wellington (Fig. 5b), raupō rises for the first time in tandem with bracken and other anthropogenic disturbance indicators early in the EMS phase. At some other sites, raupō exhibits a distinctive bimodal pattern whereby it rises early in the EMS phase, then declines before rising again later in the phase, usually mirroring fluctuations in anthropogenic disturbance indicators. At Lake Mangarakau, northwestern South Island (Fig. 5c), the raupō pollen curve, along with other wetland indicators, in particular sedges, covaries positively with the charcoal curve as well as bracken, but negatively with some native forest indicators, such as *Dacrydium cupressinum* and *Cyathea smithii.* At other sites such as Lake Te Kahika in the Far North (Fig. 5d), raupō rises to a peak late in the EMS phase, before declining gradually during the European era. At this site, and at most others in this category, other wetland or aquatic taxa show a similar stratigraphic pattern to raupō. At Lake Te Kahika, for example, sedges are first visible during the early EMS phase, but rise to maximum prominence late in the phase, in tandem with raupō.

Fig. 5. Raupō and Cyperaceae pollen and *Pteridium* spore curves along with summary ecological groups at key pollen sites indicating different temporal patterns of raupō increase (see text for description of categories). Pollen and spore counts are percentages, charcoal counts are number of specimens per cm^3 of sediment sample. (a) Category I, Lake Kereta; (b) Category II a, Lake Kohangapiripiri; (c) Category II b, Lake Mangarakau; (d) Category II c, Lake Te Kahika; (e) Category III, Lake Killarney. See Supplementary Table S1 for information on lakes including location.

Category III (EE) comprises those records (7; 12%) where raupō is either not observed or is present at comparatively low levels until the European era (EE), when it rises to peak prominence. At Lake Killarney in northwest Nelson for example (Fig. 5e), raupō pollen is absent from the record during the pre-EMS and EMS phases and is only visible in sediments dominated by introduced European plants. Collectively, of the 60 sites that contain raupō present at >1%, 87% of sites record raupō at its maximum palynological evidence post human arrival (during the EMS–EE eras), and only 5% of sites have raupō prominent during the pre-human era (Table 2). The remaining five records (8%) are unclassified, where the pattern of raupō response is hard to discern due to the incompleteness of the records (Table 2).

4.2. Principal Components Analysis

The PCA of the entire pollen dataset is presented in Fig. 6, which displays the sample and prominent taxa scores on the first two principal components. Although the first two principal components represent comparatively low levels of explanation of variability in the dataset (13.1% and 8.0%; Fig. 6), this is not unexpected given the high variability in vegetation composition across the diverse environment of Aotearoa New Zealand. Despite this variability, the 3-phase subdivision of the last ~1000 years is strongly represented by the sample scores along the first axis in particular, with pre-EMS sample scores mostly positive, EE mostly negative, and EMS scores intermediate between the other two phases. The taxa scores on the first PCA axis are consistent with this observation, with negative values for key pollen indicators for both human phases (EMS and EE) and positive values for those taxa most prominent during the pre-EMS phase. Notably, raupō clusters with the former grouping, indicating its strong stratigraphic association with human disturbance.

Fig. 6. Biplot of taxa and sample scores on the first two principal component (PC) axes for 86 pollen records from lakes in Aotearoa New Zealand, spanning approximately the last millennium. The most common pollen taxa are labelled on the diagram. The same plot but with a more complete illustration of taxa scores is available in Supplementary Information (Supplementary Fig. S1 and Supplementary Table S2).

5. Discussion

5.1. Raupō as a disturbance indicator

Our results indicate a consistent raupō response to disturbance, particularly accompanying catchment deforestation that characterises the comparatively brief human era in Aotearoa New Zealand. The strong negative PC1 score recorded for raupō pollen contrasts markedly with the positive scores recorded by native tree taxa, in particular the tall canopy and emergent podocarps (represented by *Dacrydium, Prumnopitys, Dacryacrpus* and *Podocarpus)* (Fig. 6). These PCA patterns concur with observations of the pollen diagrams, many of which show a consistent inverse relationship between tall canopy trees and raupō (Fig. 5). This relationship is not unexpected as deforestation at lake margins would have created both habitat space and a suitable light regime for raupō communities to expand.

Other processes may also have been involved, separately or in combination, depending on individual site characteristics and disturbance scenarios. From observations of the ecology and morphology of raupō (Section 2.1) and with modern observations of the genus *Typha* throughout the world (Section 2.2.2), we can speculate that enhanced nutrient and sediment fluxes accompanied catchment deforestation and that these processes also helped promote the spread of raupō in lakes across Aotearoa New Zealand. The wider Lakes380 dataset, when complete, will enable further analytical work to test this hypothesis.

Regardless of the exact mechanisms, it is apparent that in dynamic geophysical settings, which are common in Aotearoa New Zealand, these disturbance processes can occur frequently though irregularly in the natural environment, but they have been accentuated and become more pervasive once human activity begins to take effect. So much so that in essence raupō, although a native indigenous species, has become a human associate species in Aotearoa New Zealand and may be useful as an anthropological indicator in palaeoecology (Fig. 4). Raupō consistently exhibits a close, covarying relationship with *Pteridium*, the single most ubiquitous paleoecological indicator of human activity in Aotearoa New Zealand prehistory, primarily due to its favourable response to forest clearance by fire [109]. As with *Pteridium*, raupō is not a perfect indicator of human activity as reflected in the category 1 sites where it rises to prominence before independent evidence for human activity. In most of these cases, however, raupō prominence is short-lived and likely to be a response to episodic disturbance in contrast to the sustained expansion phases seen in the human era.

At many sites, the raupō response to these disturbances is tightly coupled with that of *Pteridium*, while at others a lag between the two is evident (Figs. 3, 4), pointing perhaps to local environmental factors and differing types or scales of human activity between the sites. These different raupō responses may provide clues as to the exact processes or antecedent site conditions occurring at the time and may also serve to inform wetland management plans that involve raupō (see 5.3). For example, Lake Kereta is a shallow and narrow basin, formed in a small interdune hollow that parallels the western Northland coastline. This setting and configuration is clearly favourable to raupō expansion following disturbance during and prior to human settlement (Fig. 5) and could be usefully factored into future management plans for the site.

5.2. Spatio-temporal patterns of raupō

This new dataset reveals some interesting geographical patterns in the timing of raupō expansion during the past ~1000 years (Fig. 7). Most of the sites where a raupō expansion does not occur are located at higher elevations, presumably close to or beyond the natural limits to its current distributional range (Fig. 7a). A few of these sites are also coastal localities however, suggesting that tidal influence may have promoted competing salt-tolerant species. Nevertheless, some localities that are proximal to the coast also dominate the 13 category I sites, where raupō expansion is observed before the rise of typical paleoecological indicators of early Māori influence (Fig. 7b). While localised natural disturbance events such as storms may be a likely trigger of these early raupō expansions, the intriguing possibility emerges that they could also be atypical examples of early Māori settlement impact, given the strong overall correspondence between raupō and human disturbance.

Fig. 7. Spatio-temporal patterns of raupō from 92 pollen records from lakes in Aotearoa New Zealand during the past ~1000 years. (a) sites where raupō pollen is absent or in trace amounts; (b) category I where raupō expansion is observed pre-EMS; (c) category II where raupō expansion is first observed concomitant with or during Evidence for Māori Settlement (EMS); (d) where raupō expansion is first observed during the European era (EE).

This human disturbance connection is clearly seen in the category II site distribution which encapsulates the majority of sites (Fig. 7c). Sites in this category are distributed throughout the two main islands at lower elevations and also extend to Chatham Islands. This pattern supports the notion that raupō was promoted indirectly and possibly in some cases, directly, by the rapid spread of early Māori settlers throughout most of Aotearora New Zealand. Our new paleoecological dataset shows that the

Māori settlement phase was a time of maximum expansion for raupō across Aotearora New Zealand during the last millennia, and by implication perhaps more generally. Although not apparent from Figure 6, most of these records show a subsequent raupō decline during the European era. Multiple factors for this may be at play, but the most obvious cause is the widespread draining of wetlands and associated management of lakes to promote intensified European agriculture. Consistent with this observation is the comparatively small number of sites where rāupo expansion is only observed in the European era (Fig. 7d).

5.3. Raupō as a resource in prehistory

As discussed earlier, historical and archaeological records from many parts of the world along with modern observations of traditional indigenous cultural practice attest to a rich association between people and *Typha* as a cultural resource. These reports and observations include examples showing the significance of raupō to Aotearoa New Zealand Māori, who had clearly developed a variety of important uses for the plant by the time European settlers arrived (Table 1). Today raupō is recognised as a *taonga* species for Māori [115], meaning that it's treasured not only for its utility resource value but also in terms of spiritual connection. Our lake records depicting the history of raupō over the past millennium (Fig. 7) bring an interesting perspective to these observations. Raupō expansion during the past millennium, commonly promoted by anthropogenic forest reduction or clearances and associated sediment and nutrient flux, would in turn have provided new opportunities for human exploitation of this valuable food and material resource, underlining further the human associate argument.

Combining this resource exploitation, along with the raupō pollen records that depict close coupling with human activity, raises a further question: was raupō expansion actively and deliberately practised by prehistoric Māori or was the association based on serendipity and opportunity, or both? Evidence for the former certainly exists, such as the deliberate introduction of raupō to the Chatham Islands in the early 19th century [6]. Our records also show several sites in southern, upland regions that approach or perhaps are even beyond the natural limits of raupō, yet raupō pollen curves show expansion during the early EMS phase followed by decline at sites like Lake Chalice (757 m a.s.l), Horseshoe Lake (681 m) and Lake Heron (692 m.; Fig. 4b).

5.4. Raupō: friend or foe?

It could be argued from observations of modern disturbed wetland environments, supported by the results we present here, that raupō is an invasive species in Aotearoa New Zealand, consistent with suggestions about recent *Typha* expansion in North America [2]. Whilst its capacity to rapidly colonise and spread across disturbed wetlands and lake margins promoted by increased sediment and nutrient flux is beyond dispute [20], the same attributes can be beneficial in certain circumstances. By intercepting sediment and nutrient flux at lake margins, raupō may serve as a buffer to potential contamination of a lake ecosystem. Preliminary results from Lakes380 research suggest that this may have been the case at least at some sites during the early EMS era. For example, at Lake Horseshoe, Canterbury, the marked increase in raupō during the EMS era is accompanied by distinctive changes in the diatom flora including a decline in pelagic taxa (particularly *Discostella stelligera*) and an increase in benthic/epiphytic/tychoplanktic taxa (*Pseudostaurosira brevistriata* and *Staurosira construens*) [116]. These algal changes are consistent with lake shallowing but also with increased water clarity estimated from diatom assemblages. Subsequently, during the European era, these changes are reversed and accompanied by other major compositional changes in the diatom flora that indicate progressive deterioration of water clarity. At the same time, raupō pollen levels decline progressively towards the present. Whether this recent raupō decline is a response to excessive deterioration of the lake ecosystem or due to coincidental landuse practice cannot be determined from these results and both scenarios might apply. Nevertheless, these changes are consistent with modern ecological observations of raupō-rich littoral zones acting as both a sediment trap and nutrient buffer, with variable effect dependent upon landuse activity in the catchment. Our palaeoecological data suggest raupō is an “autogenic ecosystem engineer” [117] with capacity for transitioning a lake system towards the oligotrophic end of the nutrient spectrum.

These various observations from palaeoecology bring an additional perspective to the idea that raupō can play a role in bioremediation, whilst archaeological and anthropological records attest to its wide-ranging value as a natural resource. To ignore its capacity for providing these benefits due to its invasive threat is to overlook a potentially valuable range of ecosystem services. Rather, there needs to be a robust assessment of a spectrum of ecological scenarios under which raupō may or may not be able to perform a remediation role in managed wetland recovery.

A recent example of this approach is a study of Lake Oporoa, one of the 92 sites included in the current investigation. At this shallow lake in southern North Island with strong cultural heritage [118], paleolimnology and mātauranga-a-iwi (Māori indigenous knowledge) have been applied in tandem to trace historic and prehistoric trends in water quality and lake ecosystem health. At Lake Oporoa, raupō rises to prominence during the EMS phase (i.e., category 2, cf. Fig. 5) accompanied by notable ecological changes in the lake, recorded in both the diatom and bacterial communities. Nevertheless, a more pronounced ecological shift in Lake Oporoa coincided with rapid catchment deforestation and conversion to pasture following European settlement. Further deterioration in water quality has occurred since approximately 1960 CE, when synchronous increases across all proxies indicated enhanced productivity and periods of anoxia. Raupō declines during this latter EE period after prominence in the EMS and early EE. Local Māori place high value on both its cultural significance and its role in lake ecosystem health (https://lakes380.com/lake_story/whakahokia-te-mauri-o-oporoa/), and as a consequence raupō features prominently in a proposed phytoremediation plan to restore lake water quality informed by paleolimnology and mātauranga [118].

The distinction between raupō as “friend or foe” is in large part a value judgement and, whilst beyond the scope of this paper, is now the focus of a more extensive investigation by the Lakes380 team that aims to determine the impacts of raupō expansion phases in the past using various water quality and trophic level proxies. This rich archive encompasses a range of catchment, hydrological, and lake ecosystem settings, enabling the development of scenarios under which raupō may provide net beneficial ecosystem services.

6. Conclusion and further work

A new extensive palynological dataset from New Zealand enriches understanding of the natural history and cultural affinities of *Typha orientalis* (raupō) over the past ~1000 years in Aotearoa New Zealand, a period that captures the environmental impacts of settlement. In keeping with observations of related species elsewhere, it’s consistent response to natural disturbance in freshwater wetland habitats becomes much more prominent and sustained with human settlement. The key mechanisms for disturbance response are likely to have been the creation of habitat space and increased light availability accompanying deforestation, but at some sites enhanced nutrient and sediment fluxes triggered by catchment clearances may have been involved.

As a consequence, raupō was promoted indirectly and possibly in some cases, directly, by the rapid spread of early Māori settlers throughout most of Aotearora New Zealand. The consistency of this response supports the notion that in essence raupō can be viewed as a human associate species and key anthropological indicator in Aotearoa New Zealand, at least during the Māori settlement phase. Raupō expansion would in turn have provided new opportunities for human exploitation of this valuable food and material resource, underlining further the human associate argument.

This period of maximum expansion for raupō was followed by its subsequent decline during the European era, with widespread draining of wetlands and associated management of lakes designed to promote intensified European agriculture. Our results indicate that the accompanying raupō decline in recent decades has also undermined one potential agent for mitigating the degradation of these ecosystems as a consequence of agricultural intensification by helping to transition a lake system towards the oligotrophic end of the nutrient spectrum. Conversely, we argue from these paleoecological insights that management of raupō has an important role in wetland bioremediation, whilst at the same time promoting its wide-ranging value as a natural and cultural resource. Although the focus here is on one species in Aotearoa New Zealand, our observations have wider applicability as *Typha* species worldwide share much the same ecological affinities and have typically been important to indigenous communities.

When considered alongside the anthropological and archaeological records for resource utilisation and management of *Typha* by indigenous cultures worldwide, these paleoecological records raise some important questions, in particular:

- To what extent was *Typha* deliberately introduced in prehistory to regions that were beyond its natural range and/or managed as a natural resource?
- Do antecedent eco-hydrological conditions predispose *Typha* to be an invasive threat under certain disturbance regimes that favour its spread?
- To what extent can *Typha* serve to mitigate water quality and trophic level degradation that would otherwise be promoted by high sediment and/or nutrient flux accompanying human disturbance?
- Can a deeper understanding of the ecosystem 'services' provided by *Typha* and apparent from the paleoecological record serve to promote and guide its role in wetland bioremediation programmes?
- Is wetland biodiversity promoted or depleted following *Typha* expansion?
- To what extent does traditional indigenous knowledge of *Typha* extend beyond its value as a material and food resource to an understanding of its ecological role in maintaining wetland and aquatic ecosystem health in the face of human activity?

Some of these questions can be addressed in the New Zealand context utilising the Lakes380 paleo-database, whilst the first and last call upon traditional indigenous knowledge sources. The methodologies underpinning both these independent information sources share a common philosophy of learning from the past to inform the present and future. Both need to be harnessed in unison if we are to develop a more holistic understanding of the ecological, cultural, and economic significance of *Typha*.

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References

1. Morton JF. Cattails (*Typha* spp.)—weed problem or potential crop?. Economic Botany. 1975 Jan;29(1):7-29.
2. Boers AM, Zedler JB. Stabilized water levels and *Typha* invasiveness. Wetlands. 2008 Sep;28:676-85. https://doi.org/10.1672/07-223.1
3. Shih JG, Finkelstein SA. Range dynamics and invasive tendencies in *Typha latifolia* and *Typha angustifolia* in eastern North America derived from herbarium and pollen records. Wetlands. 2008 Mar;28:1-6.
4. Hegazy AK, Abdel-Ghani NT, El-Chaghaby GA. Phytoremediation of industrial wastewater potentiality by *Typha domingensis*. International Journal of Environmental Science & Technology. 2011 Jun;8:639-48.
5. Bonanno G, Cirelli GL. Comparative analysis of element concentrations and translocation in three wetland congener plants: *Typha domingensis*, *Typha latifolia* and *Typha angustifolia*. Ecotoxicology and Environmental Safety. 2017 Sep 1;143:92-101. https://doi.org/10.1016/j.ecoenv.2017.05.021
6. Madden EA, Healy AJ. The adventive flora of the Chatham Islands. Transactions of the Royal Society of New Zealand 1959;87:221–8.
7. de Lange PJ, Heenan PB, Sawyer JSD. In: Miskelly C, editor. Chatham Islands: heritage and conservation. 2nd ed. Christchurch: Canterbury University Press; 2008. pp. 97–115.
8. de Lange PJ, Heenan PB, Rolfe JR. Checklist of vascular plants recorded from Chatham Islands. Department of Conservation, Wellington Hawke's Bay Conservancy; 2011.

9. McGlone MS. Postglacial history of New Zealand wetlands and implications for their conservation. New Zealand Journal of Ecology. 2009 Jan 1:1-23.

10. Denyer K, Peters M. The Root Causes of Wetland Loss in NZ: An analysis of public policies and processes. Prepared for the National Wetland Trust and the ELI Trust. 2020. Available from: https://www.wetlandtrust.org.nz/wp-content/uploads/2021/02/ROOT-CAUSES-OF-WETLAND-LOSS-IN-NZ_Jan-2021.pdf

11. Bansal S, Lishawa SC, Newman S, Tangen BA, Wilcox D, Albert D, et al. *Typha* (cattail) invasion in North American wetlands: biology, regional problems, impacts, ecosystem services, and management. Wetlands. 2019 Aug; 39:645-84.

12. Finlayson CM, Roberts J, Chick AJ, Sale PJ. The biology of Australian weeds. II. *Typha domingensis* Pers. and *Typha orientalis* Presl. J. Aust. Inst. Agnc. Sci. 1983;49:3-10.

13. Lishawa SC, Albert DA, Tuchman NC. Water level decline promotes *Typha* X *glauca* establishment and vegetation change in Great Lakes coastal wetlands. Wetlands. 2010 Dec;30:1085-96.

14. Travis SE, Marburger JE, Windels SK, Kubátová B. Clonal structure of invasive cattail (Typhaceae) stands in the Upper Midwest Region of the US. Wetlands. 2011 Apr;31:221-8.

15. Larkin DJ, Freyman MJ, Lishawa SC, Geddes P, Tuchman NC. Mechanisms of dominance by the invasive hybrid cattail *Typha* × *glauca*. Biological Invasions. 2012 Jan;14:65-77.

16. Larkin DJ, Lishawa SC, Tuchman NC. Appropriation of nitrogen by the invasive cattail *Typha* × *glauca*. Aquatic Botany. 2012 Jul 1;100:62-6.

17. McKee KL, Mendelssohn IA, Burdick DM. Effect of long-term flooding on root metabolic response in five freshwater marsh plant species. Canadian Journal of Botany. 1989 Dec 1;67(12):3446-52.

18. Yeo RR. Life history of common cattail. Weeds 1964;12:284-88.

19. Grace JB, Harrison JS. The biology of Canadian weeds.: 73. *Typha latifolia* L., *Typha angustifolia* L. and *Typha xglauca* Godr. Canadian Journal of Plant Science. 1986 Apr 1;66(2):361-79.

20. Hilgartner WB, Brush GS. Prehistoric habitat stability and post-settlement habitat change in a Chesapeake Bay freshwater tidal wetland, USA. The Holocene. 2006 May;16(4):479-94.

21. Boers AM, Veltman RL, Zedler JB. *Typha glauca* dominance and extended hydroperiod constrain restoration of wetland diversity. Ecological Engineering. 2007 Mar 1;29(3):232-44.

22. Asamoah SA, Bork EW. Drought tolerance thresholds in cattail (*Typha latifolia*): A test using controlled hydrologic treatments. Wetlands. 2010 Feb; 30:99-10.

23. Shay JM, De Geus PM, Kapinga MR. Changes in shoreline vegetation over a 50-year period in the Delta Marsh, Manitoba in response to water levels. Wetlands. 1999 Jun;19:413-25.

24. Wilcox DA, Kowalski KP, Hoare HL, Carlson ML, Morgan HN. Cattail invasion of sedge/grass meadows in Lake Ontario: photointerpretation analysis of sixteen wetlands over five decades. Journal of Great Lakes Research. 2008 Jan 1;34(2):301-23.

25. Newman S, Grace JB, Koebel JW. Effects of nutrients and hydroperiod on *Typha*, *Cladium*, and *Eleocharis*: implications for Everglades restoration. Ecological Applications. 1996 Aug;6(3):774-83.

26. Currie WS, Goldberg DE, Martina J, Wildova R, Farrer E, Elgersma KJ. Emergence of nutrient-cycling feedbacks related to plant size and invasion success in a wetland community–ecosystem model. Ecological Modelling. 2014 Jun 24;282:69-82.

27. Boyd CE, Hess LW. Factors influencing shoot production and mineral nutrient levels in *Typha latifolia*. Ecology. 1970 Mar;51(2):296-300.

28. Miao S, Newman S, Sklar FH. Effects of habitat nutrients and seed sources on growth and expansion of *Typha domingensis*. Aquatic Botany. 2000 Dec 1;68(4):297-311.

29. Manios T, Stentiford EI, Millner PA. The effect of heavy metals accumulation on the chlorophyll concentration of *Typha latifolia* plants, growing in a substrate containing sewage sludge compost and watered with metaliferus water. Ecological Engineering. 2003 Mar 1;20(1):65-74.

30. Jacob DL, Otte ML. Influence of *Typha latifolia* and fertilization on metal mobility in two different Pb–Zn mine tailings types. Science of the total environment. 2004 Oct 15;333(1-3):9-24.

31. Aranguren B, Becattini R, Lippi MM, Revedin A. Grinding flour in Upper Palaeolithic Europe (25000 years bp). Antiquity. 2007 Dec; 81(314):845-55.

32. Yacovleff E, Herrero FL. E1 Mundo Vegetal de los Antiguos Peruanos. Rev. Museo Nac., Lima 1934;3:243-22.

33. Bailey FM. The Queensland Flora. Pt. 5. Brisbane: Queensland Gov't; 1902.

34. Brown WH. Useful Plants of the Philippines, Vol. 1 (Tech. Bull. 10). Manila: Dept. Agr. & Nat. Res.; 1951.

35. Gott B. Cumbungi, *Typha* species: A staple Aboriginal food in southern Australia. Australian Aboriginal Studies. 1999 Jan(1):33-50.

36. Landcare Research. 2021 [Cited 2021 October 8]. Available from: https://www.landcareresearch.co.nz/tools-and-resources/collections/new-zealand-flax-collections/weaving-plants/raupo/

37. Watt G. The Commercial Products of India. London: John Murray; 1908.

38. Heyne K. De nuttige planten van Indonesie (The useful plants of Indonesia) Vol. I. 3rd ed. Bandung, Indonesia: NV Uitgeverij W. van Hoeve. 1950:713-5.

39. Harman K. 'Some dozen'raupō whares', and a few tents': Remembering raupō houses in colonial New Zealand. Journal of New Zealand Studies. 2014 Jan 1(17):39-57. https://doi.org/10.26686/jnzs.v0i17.2089.

40. Te Rūnanga o Ngāi Tahu Collection 2017. Available from: https://ngaitahu.iwi.nz/te-runanga-o-ngai-tahu/

41. Barnicoat JW. Transcript of Diary, 17th June 1843-11th October 1844. Dunedin MS: Hocken Library, 1451-53, 1844.

42. Drury H. The Useful Plants of India. 2nd ed. London: William H. Allen & Co.; 1873.

43. Dastur JF. Useful Plants of India and Pakistan. 2nd ed. Bombay: D. B. Taraporevala Sons & Co., Ltd.; 1951.

44. Heiser CB. Totoras, taxonomy, and thor. Plant Science Bulletin. 1974 Jun;20(2):22-5.

45. Winchester JH. Titicaca -- Lake at the Top of the World. Reader's Digest. 1974;104,:159-64.

46. Porcher FP. Resources of the southern fields and forests, medical, economical, and agricultural. BoD–Books on Demand; 2020 May 24.

47. Armillas P. Gardens on swamps. Science. 1971; 174:653-61.

48. Williams HW. The Māori whare: notes on the construction of a Māori house. The Journal of the Polynesian Society. 1896 Sep 1;5(3 (19):145-54.

49. Aguilar Girón JI. Relacion de Unos Aspectos de la Flora Util de Guatemala. 2nd ed. Guatemala: Tipographia Nacional; 1966.

50. Leon Hno. Flora de Cuba. Vol. 1. Contrib. Ocas. del Museo de Hist. Nat. del Colegio de la Salle No. 8. Cultural, S. A., Havana, Cuba. 1946.

51. Pulle A. Flora of Suriname. Vol. 1, Pt. 1. Afd. Handelsmuseum No. 1. Mededeeling No. 30. Kon. ver Koloniaal Inst. te Amsterdam; 1938.

52. Stahel G. De Nuttige Planten van Suriname. Bull. 57. Paramaribo: Dept. Landbouwproefstation in Suriname; 1942.

53. Standley PC, Record SJ. The Forests and Flora of British Honduras. Chicago: Pub. 350. Bot. Ser. Vol. XII, Field Mus. Nat. Hist.; 1936.

54. Wittrock GL. Edible Plants of the Pond and Water Garden. Gardeners' Book Club Ser. 2, No. 2, Organic Gardening; 1945.

55. Johnston A. Blackfoot Indian utilization of the flora of the northwestern Great Plains. Economic Botany. 1970 Jul;24(3):301-24.

56. Crowe A. A field guide to the edible plants of New Zealand. Auckland: Penguin; 2004.

57. Beveridge P. Of the Aborigines inhabiting the great lacustrine and riverine depression of the Lower Murray, Lower Murrumbidgee, Lower Lachlan and Lower Darling. Government Printer; 1884.

58. Beveridge P. The Aborigines of Victoria and Riverina. Melbourne: Hutchinson; 1889.

59. Šunde C, director. Te Pātaka Kai o Tūwiriroa. Restoring lakes and wetlands on the Taiari Plain [Film]; 2022. Airplane Studios. Available from: https://www.youtube.com/watch?v=yj2vqa37Pkc

60. Simmonds PL. The Commercial Products of the Vegetable Kingdom. London: T. F. A. Day; 1854.

61. Yanovsky E. Food Plants of the North American Indians. Washington: Misc. Pub. 237, U. S. Dept. Agr.;1936.

62. Prendergast HD, Kennedy MJ, Webby RF, Markham KR. Pollen cakes of *Typha* spp.[Typhaceae]-'lost' and living food. Economic Botany. 2000;54(3):254-5.

63. Šunde C, director. Whakahokia te mauri o Oporoa [Film]; 2022. Airplane Studios. Available from: https://www.youtube.com/watch?v=m0yXRYvRyxY

64. National Library of New Zealand. Raupō whare, Taranaki [Cited 2021 November 3]. Available from: https://natlib.govt.nz/records/22876402

65. Robinson GA. M S Journal, Mitchell Library, vol 15, A7036; 1840.

66. Demırezen D, Aksoy A. Accumulation of heavy metals in *Typha angustifolia* (L.) and *Potamogeton pectinatus* (L.) living in Sultan Marsh (Kayseri, Turkey). Chemosphere. 2004 Aug 1;56(7):685-96.

67. Maddison M, Mauring T, Remm K, Lesta M, Mander Ü. Dynamics of *Typha latifolia* L. populations in treatment wetlands in Estonia. Ecological Engineering. 2009 Feb 9;35(2):258-64.

68. Marchand L, Mench M, Jacob DL, Otte ML. Metal and metalloid removal in constructed wetlands, with emphasis on the importance of plants and standardized measurements: A review. Environmental pollution. 2010 Dec 1;158(12):3447-61.

69. Klink A. A comparison of trace metal bioaccumulation and distribution in *Typha latifolia* and *Phragmites australis*: implication for phytoremediation. Environmental science and pollution research. 2017 Feb;24:3843-52.

70. Lominchar MA, Sierra MJ, Millán R. Accumulation of mercury in *Typha domingensis* under field conditions. Chemosphere. 2015 Jan 1;119:994-9.

71. Wang YC, Ko CH, Chang FC, Chen PY, Liu TF, Sheu YS, et al. Bioenergy production potential for aboveground biomass from a subtropical constructed wetland. Biomass and bioenergy. 2011 Jan 1;35(1):50-8.

72. Elhaak MA, Mohsen AA, Hamada ES, El-Gebaly FE. Biofuel production from *Phragmites australis* (cav.) and *Typha domingensis* (pers.) plants of Burullus Lake. Egyptian Journal of Experimental Biology. 2015;11(2):237-43.

73. Rahman QM, Wang L, Zhang B, Xiu S, Shahbazi A. Green biorefinery of fresh cattail for microalgal culture and ethanol production. Bioresource technology. 2015 Jun 1;185:436-40.

74. Ahmad MS, Mehmood MA, Taqvi STH, Elkamel A, Liu CG, Xu J, et al. Pyrolysis kinetics analysis thermodynamics parameters and reaction mechanism of *Typha latifolia* to evaluate its bioenergy potential. Bioresource Technology. 2017; 245:491-01.

75. Berry P, Yassin F, Grosshans R, Lindenschmidt KE. Surface water retention systems for cattail production as a biofuel. Journal of environmental management. 2017 Dec 1; 203:500-9.

76. Rebaque D, Martínez-Rubio R, Fornalé S, García-Angulo P, Alonso-Simón A, Álvarez JM, et al. Characterization of structural cell wall polysaccharides in cattail (*Typha latifolia*): evaluation as potential biofuel feedstock. Carbohydrate polymers. 2017 Nov 1;175:679-88.

77. Carson BD, Lishawa SC, Tuchman NC, Monks AM, Lawrence BA, Albert DA. Harvesting invasive plants to reduce nutrient loads and produce bioenergy: an assessment of Great Lakes coastal wetlands. Ecosphere. 2018 Jun;9(6):e02320.

78. Svedarsky D, Grosshans R, Venema HD, Ellis-Felege SN, Bruggman J, Ostlund A, et al. Integrated management of invasive cattails (*Typha* spp.) for wetland habitat and biofuel in the Northern Great Plains of the United States and Canada: A review. Mires and Peat. 2019;25:1.

79. Grosshans R, Grieger L, Ackerman J, Gauthier S, Swystun K, Gass P, et al. Cattail Biomass in a Watershed-Based Bioeconomy: Commercial-scale harvesting and processing for nutrient capture, biocarbon and high-value bioproducts. International Institute for Sustainable Development, Winnipeg, Manitoba, Canada. 2015. Available from https://www.iisd.org/library/ cattail-biomass-watershed-based-bioeconomycommercial-scale-harvesting-and-processing.

80. Vroom RJ, Xie F, Geurts JJ, Chojnowska A, Smolders AJ, Lamers LP, et al. *Typha latifolia* paludiculture effectively improves water quality and reduces greenhouse gas emissions in rewetted peatlands. Ecological engineering. 2018 Dec 1;124:88-98.

81. de Jong M, van Hal O, Pijlman J, van Eekeren N, Junginger M. Paludiculture as paludifuture on Dutch peatlands: An environmental and economic analysis of *Typha* cultivation and insulation production. Science of the Total Environment. 2021 Oct 20;792:148161. https://doi.org/10.1016/j.scitotenv.2021.148161

82. Burrows CJ. A macrofossil flora from sediments in a lagoon marginal to Lake Coleridge, Canterbury, New Zealand. New Zealand Journal of Botany. 1995 Dec 1;33(4):519-22.

83. Burrows CJ, Russell JB. Aranuian vegetation history of the Arrowsmith Range, Canterbury I. Pollen diagrams, plant macrofossils, and buried soils from Prospect Hill. New Zealand journal of botany. 1990 Jul 1;28(3):323-45.

84. Newnham RM, Lowe DJ. Holocene vegetation and volcanic activity, Auckland isthmus, New Zealand. Journal of Quaternary Science. 1991 Sep;6(3):177-93.

85. Newnham RM, Lowe DJ, Wigley GN. Late Holocene palynology and palaeovegetation of tephra-bearing mires at Papamoa and Waihi Beach, western Bay of Plenty, North Island, New Zealand. Journal of the Royal Society of New Zealand. 1995 Jun 1;25(2):283-300.

86. Li X, Flenley JR, Rapson GL. Untangling the causes of vegetation change in a 5,300 year pollen record at Tiniroto Lakes, Gisborne, New Zealand. Vegetation history and archaeobotany. 2014 Mar;23:87-96.

87. McGlone MS. A Holocene and latest Pleistocene pollen record from Lake Poukawa, Hawke's Bay, New Zealand. Global and Planetary Change. 2002 Jul 1;33(3-4):283-99.

88. Wilmshurst JM, McGlone MS. Forest disturbance in the central North Island, New Zealand, following the 1850 BP Taupo eruption. The holocene. 1996 Dec;6(4):399-411.

89. Wilmshurst JM, Eden DN, Froggatt PC. Late Holocene forest disturbance in Gisborne, New Zealand: a comparison of terrestrial and marine pollen records. New Zealand Journal of Botany. 1999 Sep 1;37(3):523-40.

90. Wilmshurst JM, McGlone MS, Charman DJ. Holocene vegetation and climate change in southern New Zealand: linkages between forest composition and quantitative surface moisture reconstructions from an ombrogenous bog. Journal of Quaternary Science: Published for the Quaternary Research Association. 2002 Oct;17(7):653-66.

91. Newnham RM, de Lange PJ, Lowe DJ. Holocene vegetation, climate and history of a raised bog complex, northern New Zealand based on palynology, plant macrofossils and tephrochronology. The Holocene. 1995 Sep;5(3):267-82.

92. Jara IA, Newnham RM, Vandergoes MJ, Foster CR, Lowe DJ, Wilmshurst JM, et al. Pollen–climate reconstruction from northern South Island, New Zealand (41 S), reveals varying high-and low-latitude teleconnections over the last 16 000 years. Journal of Quaternary Science. 2015 Nov;30(8):817-29. https://doi.org/10.1002/jqs.2818

93. Byrami M, Ogden J, Horrocks M, Deng Y, Shane P, Palmer J. A palynological study of Polynesian and European effects on vegetation in Coromandel, New Zealand, showing the variability between four records from a single swamp. Journal of the Royal Society of New Zealand. 2002 Sep 1;32(3):507-31. https://doi.org/10.1080/03014223.2002.9517706

94. Wood J, Wilmshurst J, Newnham R, McGlone M. Evolution and ecological change during the New Zealand Quaternary. In: Shulmeister J. editor. Landscape and Quaternary environmental change in New Zealand. Paris: Atlantis Press; 2017. pp. 235-91.

95. Lyver PO, Wilmshurst JM, Wood JR, Jones CJ, Fromont M, Bellingham PJ, et al. Looking back for the future: local knowledge and palaeoecology inform biocultural restoration of coastal ecosystems in New Zealand. Human Ecology. 2015 Oct;43:681-95. https://doi.org/10.1007/s10745-015-9784-7

96. Newnham RM, Lowe DJ, Matthews BW. A late-Holocene and prehistoric record of environmental change from Lake Waikaremoana, New Zealand. The Holocene. 1998 May;8(4):443-54.

97. Newnham R, Lowe DJ, Gehrels M, Augustinus P. Two-step human–environmental impact history for northern New Zealand linked to late-Holocene climate change. The Holocene. 2018 Jul;28(7):1093-106.

98. Wilmshurst JM. The impact of human settlement on vegetation and soil stability in Hawke's Bay, New Zealand. New Zealand journal of botany. 1997 Mar 1;35(1):97-111.

99. Ritchie JC. A Holocene pollen record of boreal forest history from the Travaillant Lake area, Lower Mackenzie River Basin. Canadian Journal of Botany. 1984 Jul 1;62(7):1385-92.

100. McGlone MS. Forest destruction by early Polynesians, Lake Poukawa, Hawkes Bay, New Zealand. Journal of the Royal Society of New Zealand. 1978 Sep 1;8(3):275-81.

101. Pocknall DT, Millener PR. Vegetation near Lake Poukawa prior to the Taupo eruption. Journal of the Royal Society of New Zealand. 1984 Jun 1;14(2):151-7.

102. Fægri K, Iversen J, Kaland PE, Krzywinski K. Textbook of pollen analysis. 4th ed. Caldwell: The Blackburn Press; 1989.

103. Pocknall DT. Pollen morphology of the New Zealand species of *Dacrydium* selander, *Podocarpus* L'heritier, and *Dacrycarpus Endlicher* (podocarpaceae). New Zealand journal of botany. 1981 Mar 1;19(1):67-95.

104. Pocknall DT. Pollen morphology of the New Zealand species of *Libocedrus* Endlicher (Cupressaceae) and *Agathis* Salisbury (Araucariaceae). New Zealand journal of botany. 1981 Jul 1;19(3):267-72.

105. Pocknall DT. Pollen morphology of *Phyllocladus* LC et A. Rich. New Zealand Journal of Botany. 1981 Jul 1;19(3):259-66.

106. Large MF, Braggins JE. Spore atlas of New Zealand ferns and fern allies. Wellington: SIR Publishing N.Z.;1991.

107. Moar NT. Pollen grains of New Zealand dicotyledonous plants. Lincoln: Manaaki Whenua Press; 1993.

108. Moar NT, Wilmshurst JM, McGlone MS. Standardizing names applied to pollen and spores in New Zealand Quaternary palynology. New Zealand Journal of Botany. 2011 Jun 1;49(2):201-29.

109. McGlone MS, Wilmshurst JM, Leach HM. An ecological and historical review of bracken (*Pteridium esculentum*) in New Zealand, and its cultural significance. New Zealand Journal of Ecology. 2005 Jan 1:165-84.

110. R Core Team R. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

111. Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, et al. vegan: Community Ecology Package. R package version 2.5-6. https://CRAN.R-project.org/package=vegan

112. Wickham H. ggplot2: Elegant Graphics for Data Analysis. New York: Springer-Verlag; 2016.

113. McGlone MS. The Polynesian settlement of New Zealand in relation to environmental and biotic changes. New Zealand journal of ecology. 1989 Jan 1:115-29.

114. Wilmshurst JM, Hunt TL, Lipo CP, Anderson AJ. High-precision radiocarbon dating shows recent and rapid initial human colonization of East Polynesia. Proceedings of the National Academy of Sciences. 2011 Feb 1;108(5):1815-20.

115. Harmsworth G. Māori environmental performance indicators for wetland condition and trend. Landcare Research report LC 0102/099; 2002.

116. Gregersen R, Howarth JD, Atalah J, Pearman JK, Waters S, Li X, et al. Paleo-diatom records reveal ecological change not detected using traditional measures of lake eutrophication. Science of The Total Environment. 2023 Apr 1;867:161414.

117. Jones CG, Lawton JH, Schachak M. Organisms as ecosystem engineers. Oikos 1994; 69:373-86.

118. Short J, Tibby J, Vandergoes MJ, Wood SA, Lomax N, Puddick J, et al. Using palaeolimnology to guide rehabilitation of a culturally significant lake in New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems. 2022 Jun;32(6):931-50.

119. Pearman JK, Wood SA, Vandergoes MJ, Atalah J, Waters S, Adamson J, et al. A bacterial index to estimate lake trophic level: National scale validation. Science of The Total Environment. 2022 Mar 15;812:152385.

Supplementary Info (Figures & Tables)

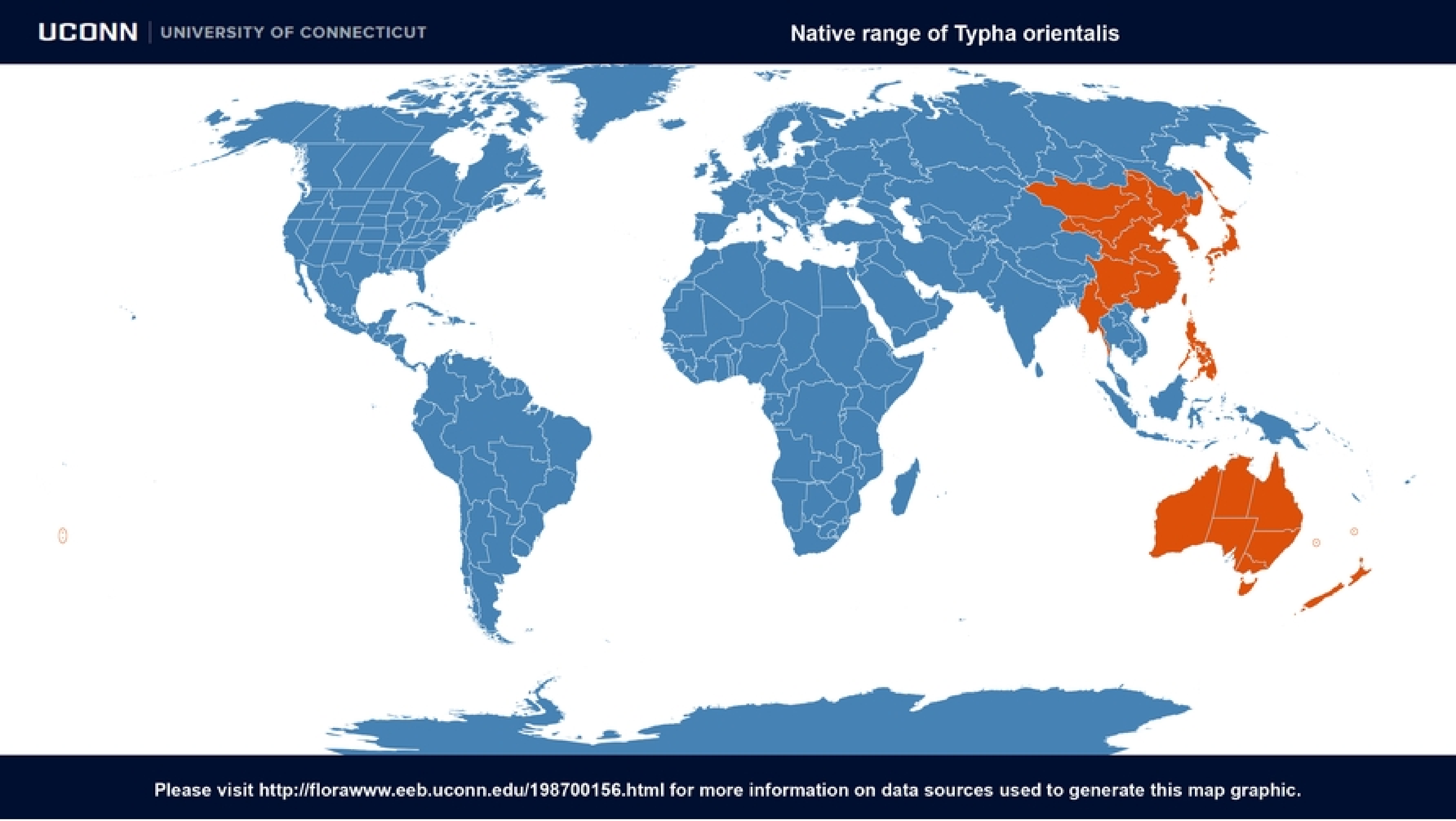
Supplementary Table S1. (uploaded separately) Co-ordinates and environmental data for the 92 study lakes. The trophic states for each lake are estimated using the surface bacteria trophic index (SBTI) [119]. The category was defined by distribution of raupō pollen% from each sediment core, and lakes where maximum raupō pollen% were either <1% or absent were displayed as NA. (Please find the excel file in attachment).

Supplementary Fig. S1 Biplot of taxa and sample scores on the first two principal component (PC) axes for 86 pollen records from lakes in Aotearoa-New Zealand spanning approximately the last millennium. The names of the labelled pollen taxa are listed in Supplementary Table S2. Zones as defined in Table 2.

Supplementary Table S2. Meaning of labels used in the PCA biplot (Supplementary Fig. S1). Label prefix refers to ecological taxon groupings, i.e.: E=Exotic, T=Tall trees, S=Small trees and shrubs, H=Herbs, W=Wetland taxa, A=Aquatics, F=Ferns, C=Charcoal.

Label	Taxon	Label	Taxon
E1	*Alnus*	S7	Fabaceae
E2	Cupressaceae	S8	*Leptospermum* type
E3	*Pinus*	S9	*Muehlenbeckia*
E4	*Plantago*	S10	*Myrsine*
E5	*Rumex*	S11	*Plagianthus*
E6	*Taraxacum* type	S12	*Pseudopanax*
T1	*Agathis australis*	S13	*Pseudowintera*
T2	*Dacrycarpus dacrydioides*	S14	Rosaceae
T3	*Dacrydium cupressinum*	H1	Apiaceae

T4	*Fuscospora*	H2	Chenopodiaceae
T5	*Halocarpus*	H3	Poaceae
T6	*Lophozonia menziesii*	W1	Centrolepidaceae
T7	*Metrosideros*	W2	Cyperaceae
T8	*Nestegis*	W3	*Gleichenia*
T9	*Phyllocladus*	W4	*Isoetes*
T10	*Podocarpus*	W5	Restionaceae
T11	*Prumnopitys ferruginea*	W6	*Typha*
T12	*Prumnopitys taxifolia*	A1	*Myriophyllum*
T13	*Salix*	A2	*Potamogeton*
T14	*Weinmannia*	F1	*Cyathea* spp.
S1	*Ascarina lucida*	F2	*Dicksonia* spp.
S2	Asteraceae	F3	Ferns
S3	*Coprosma*	F4	Lycopodiaceae
S4	*Coriaria arborea*	F5	*Pteridium esculentum*
S5	*Dodonaea viscosa*	C	Charcoal
S6	Ericaceae		



Native range of Typha orientalis

Please visit http://florawww.eeb.uconn.edu/198700156.html for more information on data sources used to generate this map graphic.

Figure 1

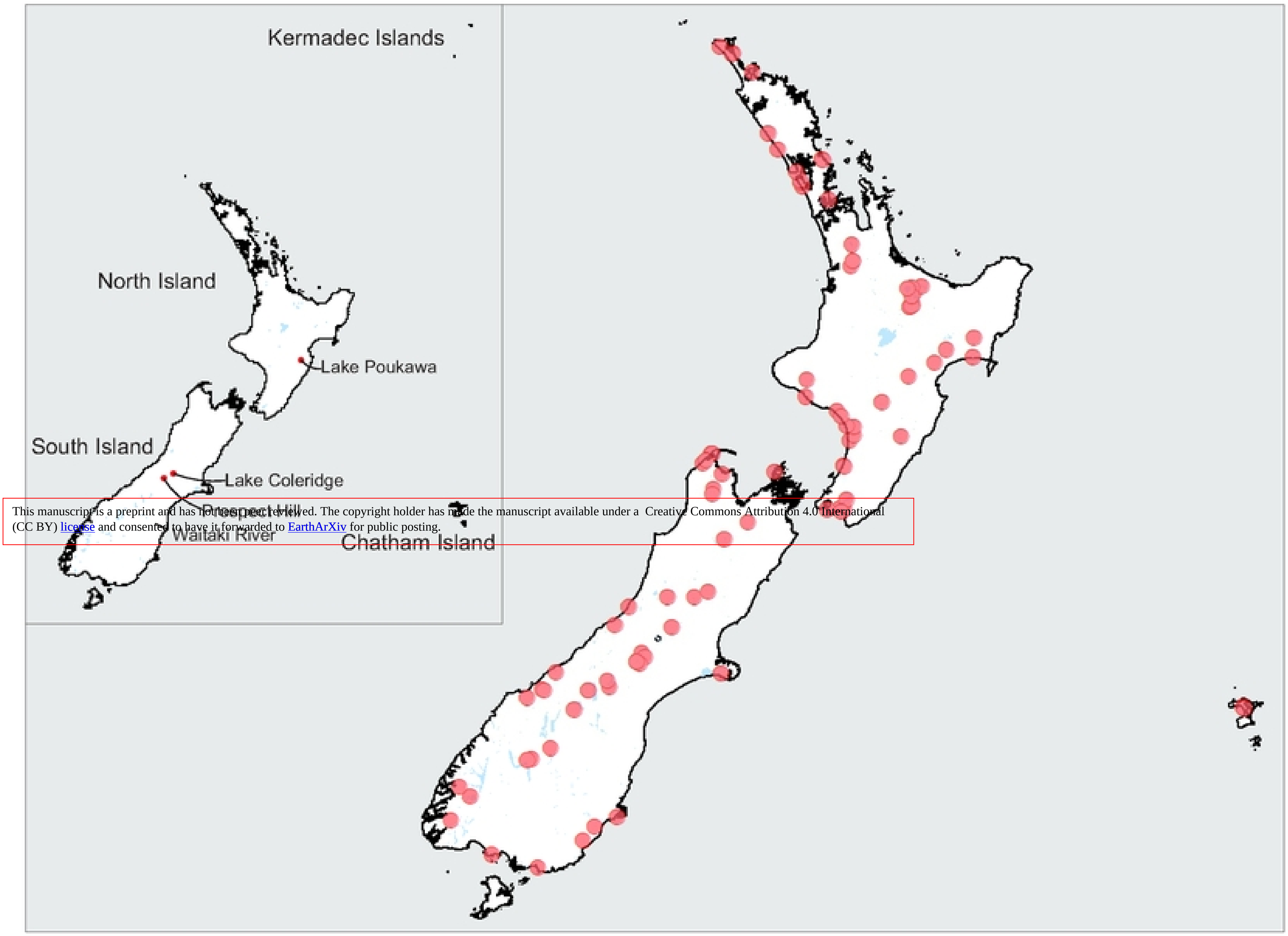

Kermadec Islands
North Island
Lake Poukawa
South Island
Lake Coleridge
Prospect Hill
Waitaki River
Chatham Island

Figure 2

Figure 3

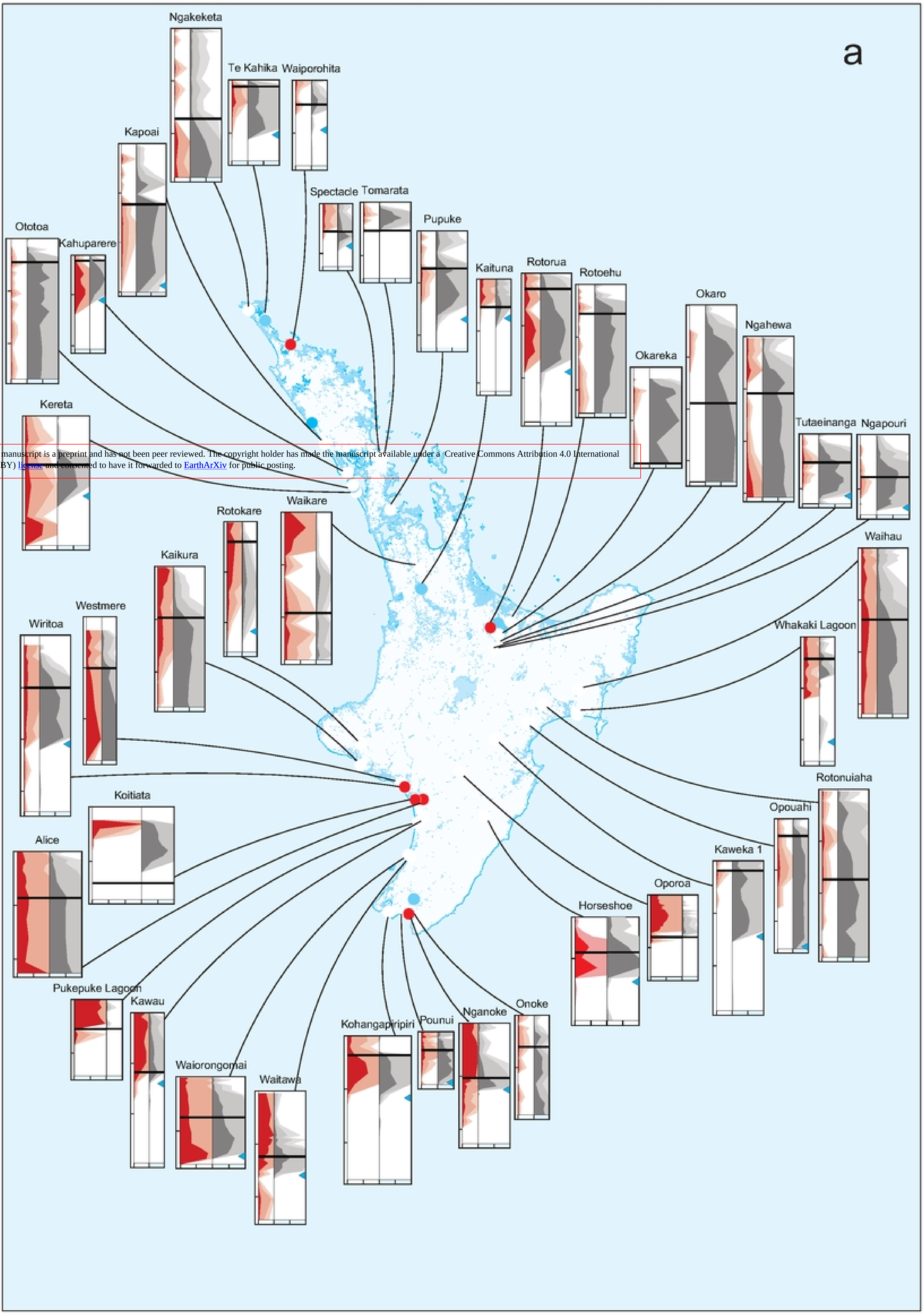

a
Ngakeketa
Te Kahika
Waiporohita
Kapoai
Spectacle
Tomarata
Pupuke
Ototoa
Kahuparere
Kaituna
Rotorua
Rotoehu
Okaro
Ngahewa
Okareka
Tutaeinanga
Ngapouri
Kereta
Waikare
Rotokare
Kaikura
Westmere
Wiritoa
Waihau
Whakaki Lagoon
Koitiata
Alice
Rotonuiaha
Opouahi
Kaweka 1
Oporoa
Horseshoe
Pukepuke Lagoon
Kawau
Waiorongomai
Waitawa
Kohangapiripiri
Pounui
Nganoke
Onoke

Figure 4a

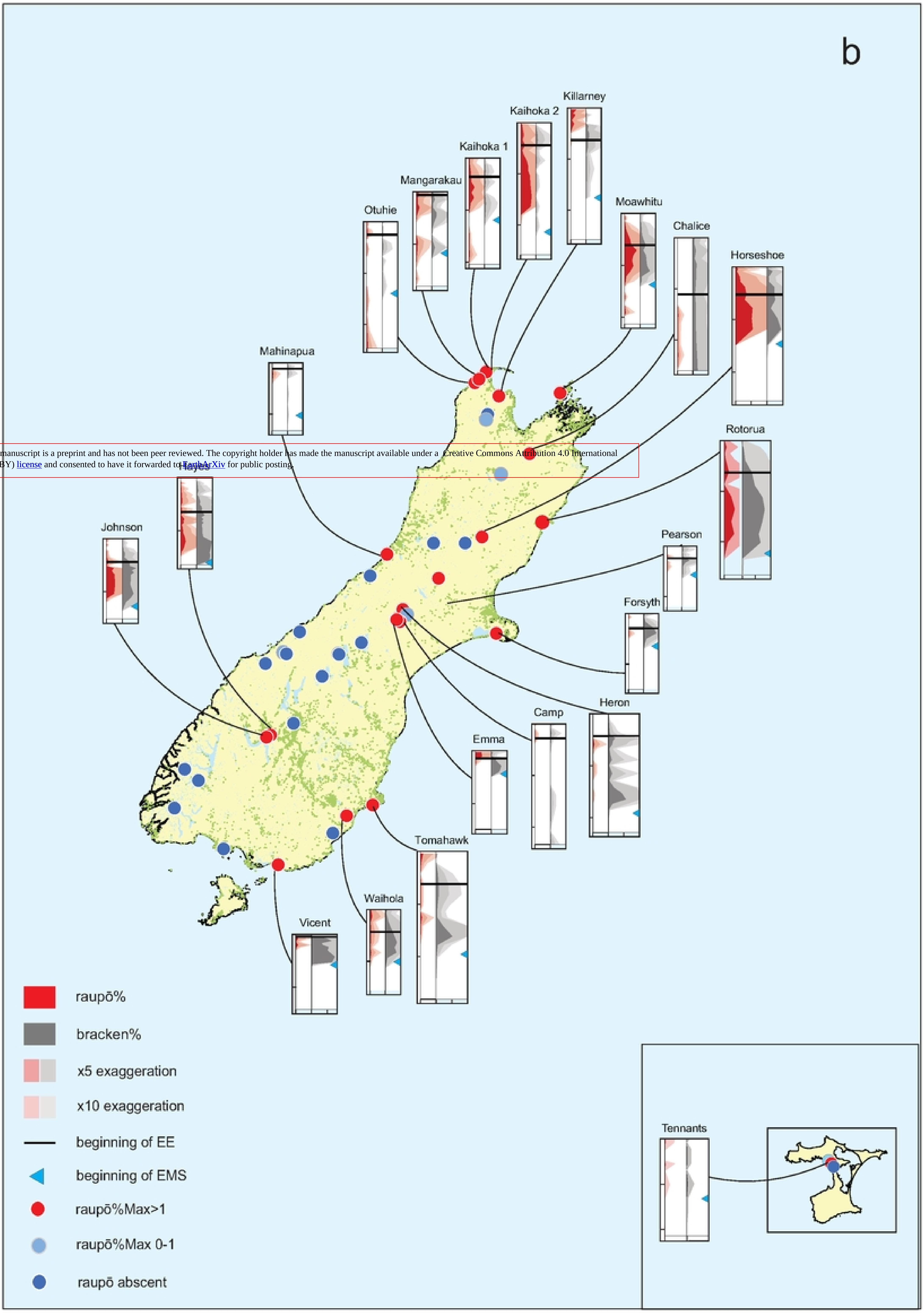

b
Killarney
Kaihoka 2
Kaihoka 1
Mangarakau
Otuhie
Moawhitu
Chalice
Horseshoe
Mahinapua
Rotorua
Hayes
Johnson
Pearson
Forsyth
Heron
Camp
Emma
Tomahawk
Waihola
Vicent
Tennants
raupō%
bracken%
x5 exaggeration
x10 exaggeration
beginning of EE
beginning of EMS
raupō%Max>1
raupō%Max 0-1
raupō absent

Figure 4b

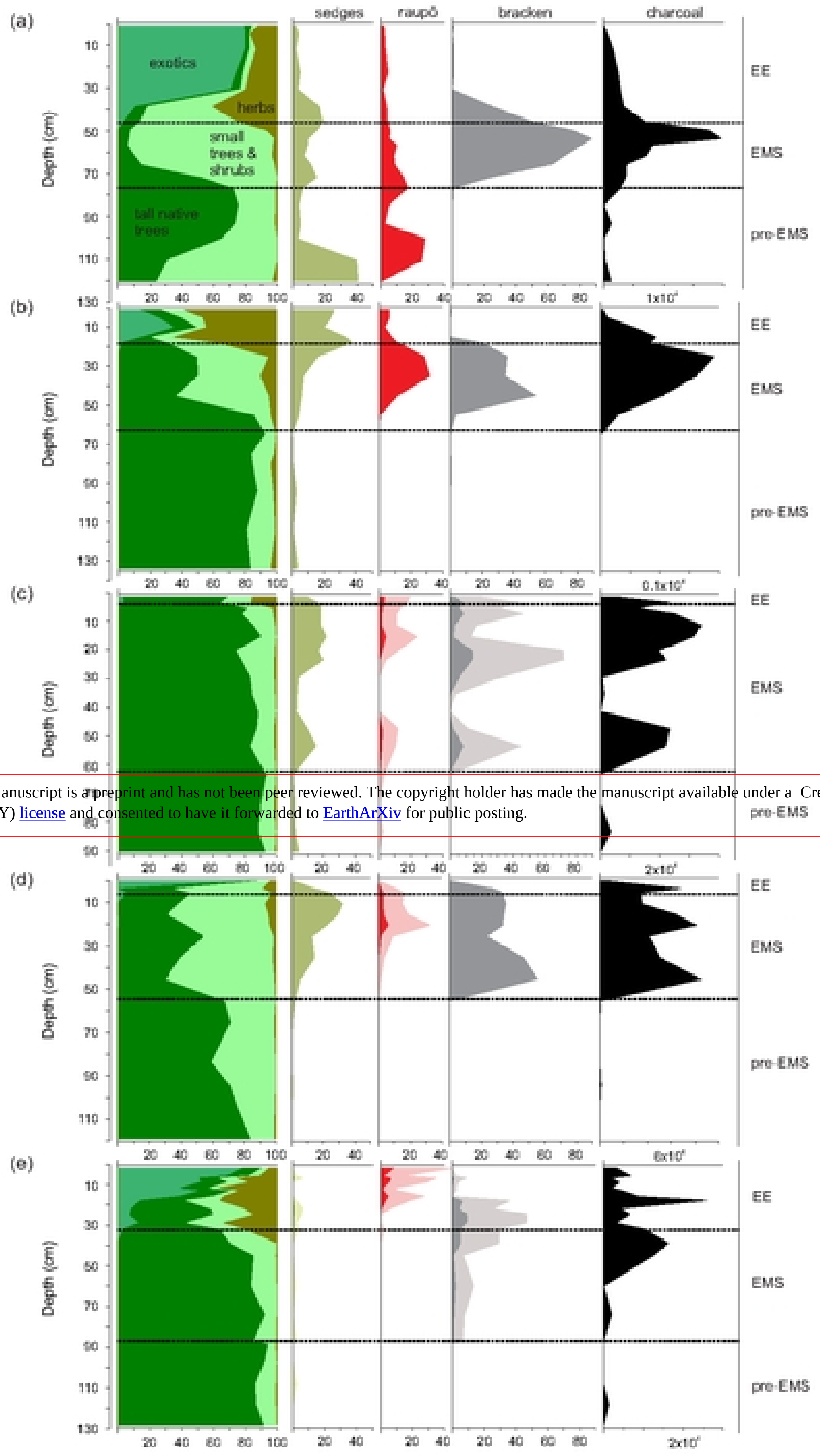

(a)
sedges
raupō
bracken
charcoal
exotics
herbs
small trees & shrubs
tall native trees
Depth (cm)
10
30
50
70
90
110
130
EE
EMS
pre-EMS
20
40
60
80
100
1x10
(b)
0.1x10
(c)
10
20
30
40
50
60
70
80
90
2x10
(d)
6x10
(e)
2x10

Figure 5

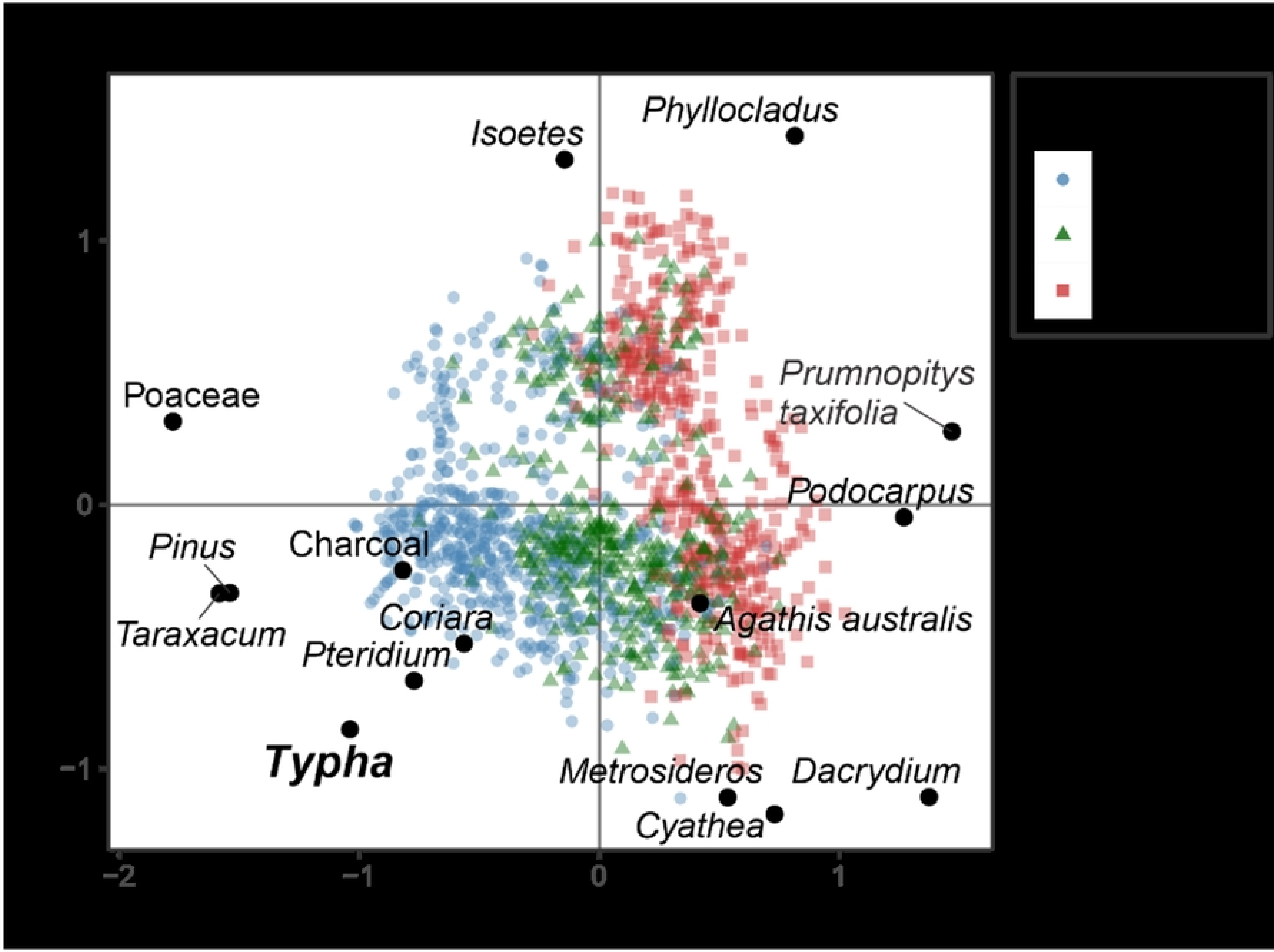

Phyllocladus
Isoetes
Poaceae
Prumnopitys taxifolia
Podocarpus
Pinus
Charcoal
Taraxacum
Coriara
Pteridium
Agathis australis
Typha
Metrosideros
Dacrydium
Cyathea
1
0
−1
−2
−1
0
1

Figure 6

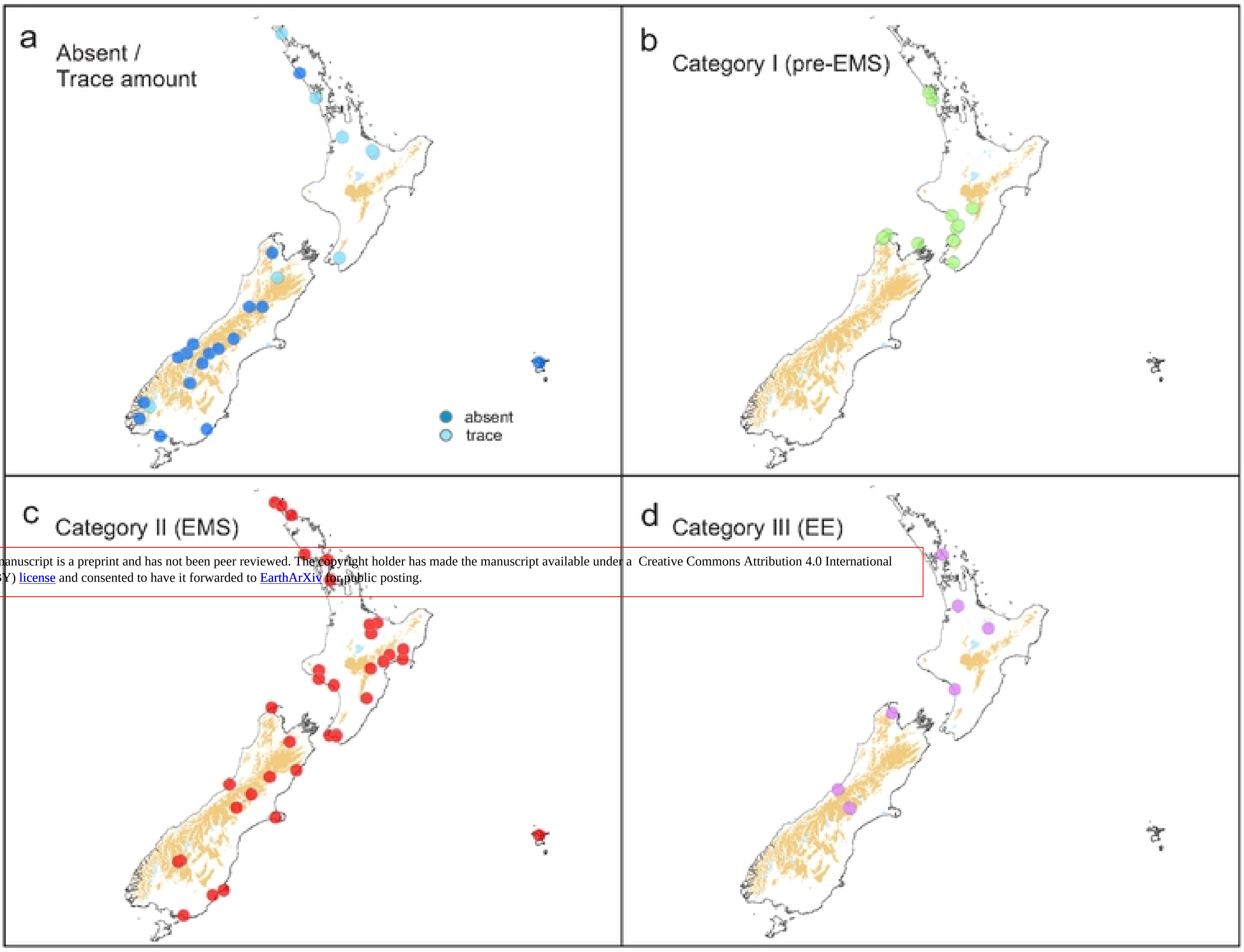

a
Absent /
Trace amount
absent
trace
b
Category I (pre-EMS)
c
Category II (EMS)
d
Category III (EE)

Figure 7