Looking Back for the Future: Local Knowledge and Palaeoecology Inform Biocultural Restoration of Coastal Ecosystems in New Zealand

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Abstract We combine local knowledge of elders and environmental practitioners from two indigenous Māori communities and pollen evidence in soil cores from two islands and two mainland coastal sites to inform the planning of coastal ecosystem restoration initiatives in New Zealand. The Māori participants desired ecosystems that delivered cultural (e.g., support for identity), social (e.g., knowledge transfer), economic (e.g., agroecology) and environmental (e.g., biodiversity protection) outcomes to their communities. Pollen records identified three periods when vegetation was dominated by different taxa: (1) Pre-human (<AD c.1280) – forest dominated by native conifers, angiosperms and nīkau palm (*Rhopalostylis sapida*); (2) Māori settlement (AD c.1280–1770) – scrub and bracken fern (*Pteridium esculentum*); and (3) European settlement (post-1770) – *Metrosideros excelsa* forest with harakeke (*Phormium* sp.), raupō (*Typha orientalis*), grasses (Poaceae), exotic plantation conifers (Pinaceae), and agricultural weeds. A fourth, aspirational system that integrated human activities such as agriculture and horticulture with native forest was conceptualized. Our approach emphasizes the importance of placing humans within nature and the reciprocity of environmental and social well-being.

Keywords Biocultural restoration · Biodiversity · Ecosystem states · Māori · Pollen · New Zealand

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Introduction

Declines in biodiversity and cultural diversity remain global issues despite international programs, platforms and conventions designed to slow or reverse losses (Millennium Assessment 2005; Butchart *et al.* 2010; Pimm *et al.* 2014). In response to biodiversity loss, restoration initiatives have increased, but success varies widely (Hobbs 2007) and is often "hampered by an incomplete or flawed concept of historical 'reference' used when choosing or constructing a target ecosystem or landscape to restore to" (Balaguer *et al.* 2014). Restoration ecology is complex but broadly refers to shifting landscapes (or waterscapes) and their supporting ecosystems through a series of different states. Each state is defined (theoretically or by existing examples, palaeoecological evidence or oral histories) by some combination of variables (e.g., species composition) considered important for the functioning of the system (Suding *et al.* 2004; Suding and Hobbs 2008). These states are used as constructs, from which resources (e.g., labor, money) required to shift from one state to another can be evaluated and potential obstacles identified. The potential trajectories of change predicted for a system can be described using conceptual state-and-transition models, which represent graphically how key factors influence the shifts between system states (Hobbs and Norton 1996).

Biodiversity management and restoration has a history of strong ecological agendas with the overarching goal of

restoring ecological integrity (Parrish *et al.* 2003; Hobbs and Cramer 2008; Devoto *et al.* 2012; Wortley *et al.* 2013). The main intent of these initiatives has been to remove threats (e.g., invasive plants and animals; Zavaleta *et al.* 2001; Innes and Saunders 2011) and in some cases reintroduce locally extirpated iconic or endangered species (Restani and Marzluff 2002; Higgs 2005; Perry 2010). Although an increasing number of protected area management plans are taking account of indigenous peoples' priorities (e.g., Department of Conservation 2008; Davies *et al.* 2013) questions remain about the effectiveness of "people-oriented approaches to conservation" (Wilshusen *et al.* 2002). This is largely justified on the basis that human activities have an adverse effect on rare species and habitats, threatened species recovery efforts, and/or conservation and scientific priorities (Schwartzman *et al.* 2000).

In contrast to ecological-integrity-driven biodiversity restoration, restoration goals of indigenous peoples often accentuate the importance of human agency and connection with the environment (Janzen 1988; Stephenson *et al.* 2014). This worldview is shaped by cultural institutions, norms, genealogy and ethics, natural resource use, and in former European colonies like New Zealand (NZ), Australia and Canada, the colonialization experience. Together these elements can form the cultural foundation for ecological restoration (Long *et al.* 2003). In such cases, emphasis can be on restoration goals that support the revival of traditional foods, materials, language, or spiritual practices and ceremonies for indigenous communities (Higgs 1997; Garibaldi and Turner 2004). In some instances this might include tolerance of non-indigenous species if they are deemed useful or valuable (Jones *et al.* 2012). These goals form the basis of "eco-cultural" (Martinez 1995) or "biocultural" (Maffi and Woodley 2010) restoration initiatives.

At the onset of this study we were approached by two Māori (NZ's indigenous Polynesian population) tribal authorities with interests in restoring coastal and offshore island ecosystems in the northern region of NZ who required data on past ecosystem states to inform their restoration plans. As well as science-based approaches, they expressed a strong desire to use their local knowledge systems in planning restoration goals, which included maintenance of some current land use practices. We therefore considered a biocultural approach to ecosystem restoration planning by synthesizing local indigenous knowledge within each community with fossil-pollen records from soil profiles taken from representative sites in the targeted areas. We thus generated restoration goals with both ecological and cultural perspectives of system states and a biocultural future. While palaeoecological studies (i.e., reconstructing past ecosystems using fossil records) are increasingly used to provide insights into past-states (Coffey *et al.* 2011; Vegas-Vilarrúbia *et al.* 2011; Chambers *et al.* 2013), such pre-disturbance baselines are rarely well understood or defined in restoration projects (Froyd and Willis 2008; Wilmshurst *et al.* 2014). We challenge the conventional restoration ethos of

restoring ecological integrity by providing goals characterized only by a biocultural approach. Finally, we use information from both knowledge systems to conceptualize a state-and-transition model for the focal coastal ecosystems. The model also identifies drivers that may potentially hinder or even block successional trajectories toward achieving restoration goals (Standish *et al.* 2009; Bellingham *et al.* 2010), and the interventions required to overcome these barriers.

Methods

Study Sites and Māori Tribal Areas

We worked within the tribal areas of two Māori *iwi* (tribes), Ngātiwai and Ngātikahu ki Whangaroa, on the warm temperate east coast of the Northland region of NZ (Fig. 1). As of 5 March 2013, 5667 people identified themselves as being of coastal Ngātiwai descent (Statistics NZ 2013). Ngātikahu ki Whangaroa is a collective of three *hapū* (subtribes) with approximately 1750 members (Office of Treaty Settlements 2007). The collective owns the offshore island of Ririwhā (Stephensons Island; Fig. 1), which is managed primarily as a sheep (*Ovis aries*) farm. Members of both iwi rely heavily on resources from their coastal and marine environments and therefore have a keen interest in restoring coastal sites while at the same time promoting economic and employment opportunities.

Collection of Local Knowledge

We conducted interviews with four women and 12 men from Ngātiwai, and one woman and four men from Ngātikahu ki Whangaroa. The men ranged in age from 48 to 85 years and the women from 68 to 80 years. One interview was conducted with three members (two men and one woman) of one Ngātiwai family. Subjects were mostly elders and tribal environmental managers or natural resource users identified by the community members as having lived most of their lives along the coast and consequently had extensive knowledge relating to coastal environments. Interviewees were selected based on their practical experiences of harvesting natural resources (e.g., *rongoā* (medicinal plants), kiore (Pacific rats, *Rattus exulans*), grey-faced petrel (muttonbird; *Pterodroma macroptera gouldi*) chicks, cultivation of root crops such as kūmara (sweet potato, *Ipomoea batatas*); and sheep farming. We acquired a spatial cross-section from the community with some interviewees living on offshore islands (but not Tawhiti Rahi) and others on the mainland. The age range allowed for perspectives and knowledge from Māori who relied on the coastal environments in quite different ways. The older interviewees (70 years or older; *n* = 16) were raised when Māori communities relied heavily on natural resources harvested from coastal environments and horticulture and agriculture on small farm units. The 'younger' interviewees (<70 years of age; *n* = 5)
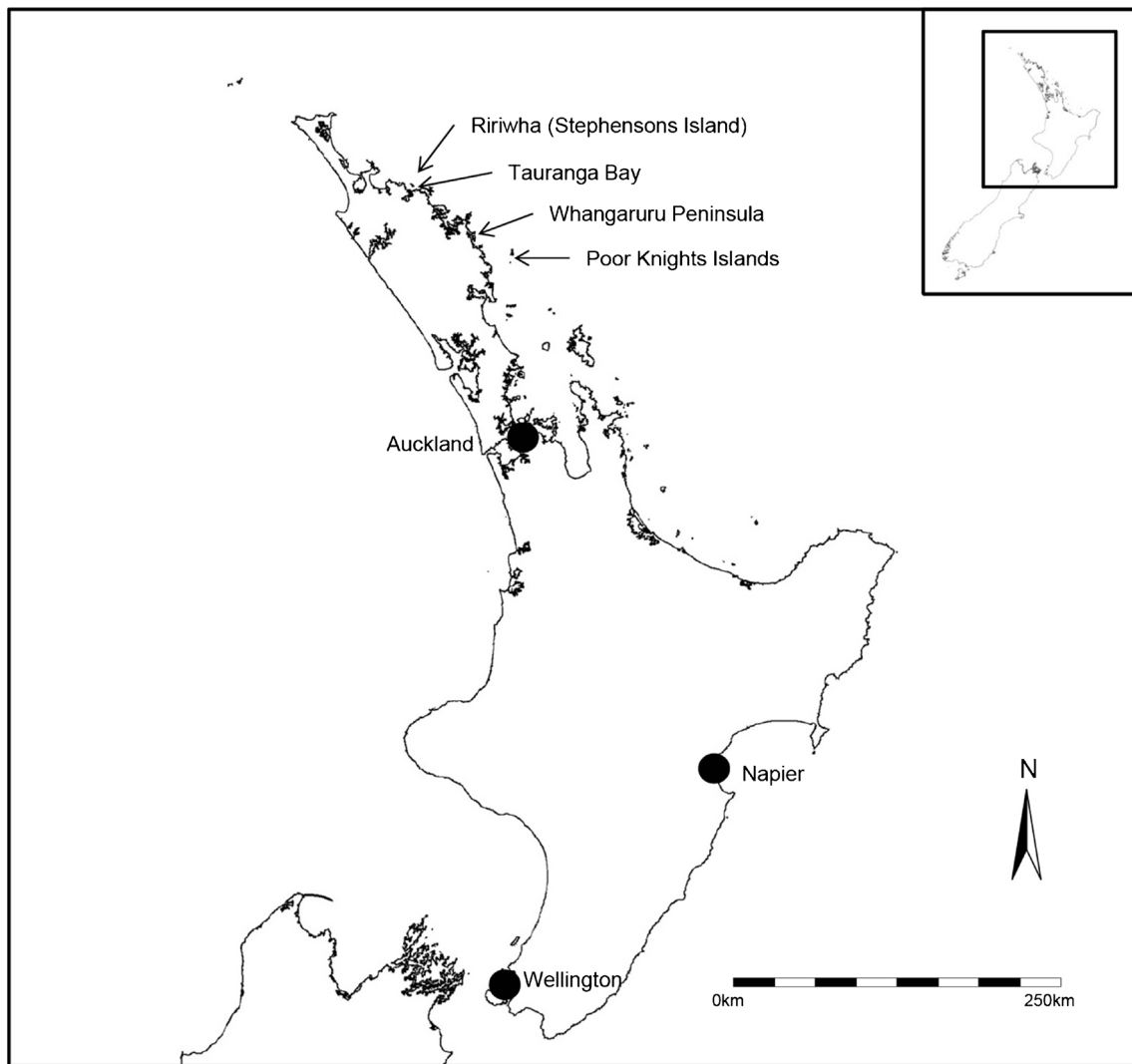
Fig. 1 Sampling sites on two island (Ririwhā and Tawhiti Rahi) and two coastal mainland sites (Tauranga Bay and Whangaruru Peninsula) in Northland, New Zealand

grew up with the rise of the service industry, greater availability of food from shops and migration of Māori from rural areas into towns and cities. For them purchased food replaced reliance on foods harvested from the environment.

We conducted semi-structured interviews to allow for more "natural" conversation to occur and for unanticipated insights to emerge (Huntington 2000; Telfer and Garde 2006). Since all interviewees spoke English as either a first or second language all interviews were conducted primarily in English, and took place between April 19 2010 and April 19 2011, ranging from 0.5 to 2 h. All interviews were recorded on digital audio and transcribed verbatim. We categorized parts of interviews for further assessment according to the themes: (1) *biodiversity*—faunal and floral presence and composition histories; (2) *restoration*—guidelines, goals and practices for restoration; (3) *land use*—use of fire to clear land, agricultural and horticultural practices and exotic pine forestry; and (4) *whakapapa* (genealogy).

Long-term Vegetation Records: Soil Core Collection and Analysis

We reconstructed long-term vegetation records from plant microfossils preserved in peat cores taken from one island and one coastal mainland site within each tribal region (Table 1, Fig. 1). The Whangaruru Peninsula and the island of Tawhiti Rahi (Poor Knights Islands) are within Ngātiwai's tribal region, while Tauranga Bay and the island of Ririwhā are in Ngātikahu ki Whangaroa's tribal region.

We collected peat cores using a D-section hand corer and transferred them to plastic drainpipes in the field, and sealed them with plastic wrap to prevent contamination with modern pollen. The maximum depths of peat collected were 220 cm at Ririwhā; 200 cm at Tauranga Bay; 85 cm at Tawhiti Rahi; and 200 cm at Whangaruru. We sub-sampled the cores at 5-cm intervals (≤5-mm vertical slices) for pollen analysis in a clean laboratory environment. Preparation of microscope slides for

Table 1 General site descriptions and affiliated Māori tribes at sites where soil pollen cores were sampled at two island (Ririwhā and Tawhiti Rahi) and two coastal mainland (Tauranga Bay and Whangaruru Peninsula) locations in Northland, NZ

	Site	Latitude, longitude	Dominant vegetation surrounding coring site	Local vegetation description at coring site	Geology	Mean annual temperature (°C)[a]	Mean annual rainfall (mm)[b]
Ririwhā (Ngātikahu ki Whangaroa)	Island	34° 58'S 173° 47'E	Grazed *Cenchrus clandestinus* pasture with small remnants of *Metrosideros excelsa* on cliffs	*Typha orientalis* wetland	Metasedimentary (Waipapa terrane)[c]	15.5	1695
Tawhiti Rahi (Ngātiwai)	Island	35° 27'S 174° 44'E	*Metrosideros excelsa* forest with angiosperm understory	*Metrosideros excelsa* with *Phormium tenax* understory	Miocene rhyolite[d]	15.9	1310
Tauranga Bay (Ngātikahu ki Whangaroa)	Coastal mainland	35° 0'S 173° 47'E	Pasture with degraded remnant of lowland forest (*Leptospermum scoparium*) within 500 m	*Typha orientalis* wetland	Metasedimentary (Waipapa terrane)[d]	15.5	1695
Whangaruru Peninsula (Ngātiwai)	Coastal mainland	35° 22'S 174° 22'E	Exotic conifer forest, with native forest within 2 km	Wetland dominated with sedges, rushes and exotic grasses	Metasedimentary (Waipapa terrane)[d]	15.5	1432

[a] Rainfall proxies: Ririwhā and Tauranga Bay – Kaeo; Tawhiti Rahi – Whangārei; Whangaruru – Russell

[b] Temperature proxies: Ririwhā and Tauranga Bay – Kerikeri; Tawhiti Rahi – Whangārei; Whangaruru – Purerua. Both are average values 2002–12 ex the National Climate Database (http://cliflo.niwa.co.nz/)

[c] Adams *et al.* (2009)

[d] Hayward (1991)

pollen analysis followed standard procedures (Moore *et al.* 1991), with heavy liquid separation using LST (lithium heteropolytungstates in water) replacing the hydrofluoric-acid step. We counted pollen and spores until we reached a pollen sum of all dryland plants of at least 250 grains. We identified palynomorphs using the NZ pollen and spore reference collection (Landcare Research, Lincoln, NZ) and by morphological features (Large and Braggins 1991; Moar 1993). Nomenclature for pollen taxonomic groups on the pollen diagrams follows Moar *et al.* (2011) and in all subsequent text we consider the most likely local species represented by each pollen group. We used charcoal analysis to reconstruct past fire histories for each site and followed standard methods (Whitlock and Larsen 2001) with all particles of charcoal >125 μm and >250 μm in a 1-ml volume of sediment counted.

Bulk peat or macrofossil samples from each core were submitted for radiocarbon dating by accelerator mass spectrometry (AMS) (Radiocarbon Dating Laboratory, University of Waikato, Hamilton, NZ). Sample pre-treatment comprised washes in hot hydrochloric acid, rinsing, and multiple washes in hot sodium hydroxide. The insoluble fraction remaining was treated with hot hydrochloric acid, filtered, rinsed, dried and graphitized. Radiocarbon dates were calibrated into calendar years with the R package Bchron (Parnell *et al.* 2008) using the ShCal04 calibration curve (McCormac *et al.* 2004). We constructed Bayesian age–depth models using stochastic linear interpolations between calibrated radiocarbon dates in Bchron.

We divided the pollen records into three periods – pre-human (before about AD 1280; Wilmshurst *et al.* 2008), Māori settlement (ca. 1280–1770) and European settlement (after 1770) – using our age–depth models and palynological markers (widely recognized changes in vegetation and charcoal composition associated with each settlement phase; e.g., McGlone and Wilmshurst 1999). The time categories assist in the description and interpretation of the pollen records and provide three generic vegetative periods as potential restoration states; one "natural" (i.e., pre-human), the others cultural.

Results

Using Long-Term Vegetation Records to Understand Past Coastal Ecosystem States

The main pollen types and charcoal records for all four sites are summarized in Table 2 and Fig. 2 (see also Wilmshurst *et al.* 2014). The timing of vegetation composition changes was consistent in the sites and contemporaneous with other sites in the region (Elliot *et al.* 1998; Horrocks *et al.* 2002; Wilmshurst *et al.* 2014) and across NZ (McGlone and Wilmshurst 1999). Basal calendar ages for the cores were approximately 500 BC for Tawhiti Rahi, AD 1400 for

Table 2 Summary of vegetation community composition at the four study sites, as revealed by pollen analysis, during the three main settlement phases (pre-human, Māori, and European) and the main drivers of vegetation change

Settlement phase	Dominant drivers	Tauranga Bay	Ririwhā	Whangaruru	Tawhiti Rahi
Pre-human	Natural disturbance (e.g., small fires, cyclones)	Tall conifer forest dominated by *Dacrydium cupressinum* and *Prumnopitys taxifolia*, *P. ferruginea* with a diverse angiosperm understory dominated by *Metrosideros* sp., *Elaeocarpus* sp., *Laurelia novae-zelandiae*, *Griselinia lucida*, *Corynocarpus laevigatus*, *Ascarina lucida* and tree ferns (*Cyathea* spp.). Wetland vegetation dominated by Cyperaceae and *Leptospermum scoparium*.		Tall conifer forest dominated by *Dacrydium cupressinum*, and *Prumnopitys taxifolia*, *Podocarpus* spp. and *Libocedrus plumosa*. *Metrosideros* sp. common. Smaller trees represented by *Ascarina lucida*, *Streblus* spp., *Rhopalostylis sapida* and *Cyathea* spp. *Leptospermum scoparium* abundant but declines toward the top of the period.	Tall forest dominated by *Rhopalostylis sapida* palm, *Cordyline* spp., *Nestegis* spp., *Dacrydium cupressinum* and numerous angiosperm trees and shrubs, with an understory dominated by *Macropiper excelsum*, *Coprosma* spp. and *Myrsine* spp., with *Phormium tenax*, Poaceae, ground ferns and epiphytic ferns.
Māori settlement c. AD 1280	Human arrival, anthropogenic fire, introduction of mammals (kiore, dogs), hunting, gardening	Tall forest declines and is replaced by ground ferns, in particular *Pteridium esculentum*. *Typha orientalis*, Poaceae and charcoal become more common, whereas *Leptospermum scoparium* declines. Lactucaceae, possibly the cultivated *Sonchus kirkii*, increases in this zone.	Remains of forest decline, replaced with open vegetation dominated by *Pteridium esculentum*, *Coriaria arborea*, and ground ferns, *Cyathea* spp., and small amounts of Poaceae. *Leptospermum scoparium* is the dominant tall vegetation, with other shrubs, including *Coprosma* spp., less common.	Many forest taxa disappear, including *Streblus* spp., *Myrsine* spp. and *Ascarina lucida*. Formerly dominant *Metrosideros*, *Dacrydium cupressinum* and *Prumnopitys taxifolia* decline rapidly, although small forest remnants persist. *Pteridium esculentum* and other ground ferns dominate and *Cyathea* spp. becomes more abundant at the top of the period.	Tall forest declines, and is replaced by seral taxa dominated by *Pteridium esculentum* and *Leptospermum scoparium*. *Macropiper excelsum* s.l. remains common. *Haloragis* spp., Lactucaceae, Poaceae, Cyperaceae and *Apodasmia similis* all increase in this period. *Typha orientalis* appears for the first time.
European settlement c. AD 1800	Anthropogenic fire, erosion, introduced mammals (feral herbivores, domestic livestock, numerous mammalian predators), agriculture, forestry, weed invasion	Remnant forest, *Leptospermum scoparium* and *Pteridium esculentum* decline, and are replaced by Poaceae, Lactucaceae, agricultural weeds and pine plantations. Local wetland taxa expand, in particular several types of Cyperaceae and *Typha orientalis*.	Many forest types recorded in the Māori period are not recorded again, such as *Agathis australis*, *Rhopalostylis sapida* and *Prumnopitys taxifolia*. *Leptospermum scoparium*, *Pteridium esculentum* and *Coriaria arborea* decline rapidly and are replaced by Poaceae and agricultural weeds such as *Taraxacum* spp. and *Rumex* spp.. Wetland taxa become dominated by *Schoenus* and *Typha orientalis*. Tree ferns *Dicksonia* spp. and *Cyathea* spp. become more abundant.	Many forest elements, such as *Metrosideros* spp., *Weinmannia silvicola*, *Knightia excelsa* and *Coprosma* spp., disappear. *Pteridium esculentum* and *Leptospermum* decline, and are replaced by Poaceae, *Coriaria arborea*, *Taraxacum* spp. and exotic Pinaceae. *Typha orientalis* most abundant in this period.	*Metrosideros excelsa* forest becomes dominant toward the present, at the same time as the seral vegetation associated with the Māori period declines.

Ririwhā (only ca. 150 years after initial arrival of Māori), AD 568 for Tauranga Bay, and the oldest was 2600 BC for Whangaruru—reflected in the much longer period of pre-human forest cover in the pollen diagram for this site (Fig. 2). The dominant vegetation cover for the pre-human, Māori and European settlement periods of the pollen records are summarized in Table 2 and in the descriptions below:

In the pre-human period, lowland coastal forest grew at the sites dominated by conifers (e.g., *Dacrydium cupressinum*) with a diverse range of angiosperm trees and shrubs (e.g., *Metrosideros* spp., *Coprosma* spp., *Macropiper excelsum*), nīkau palm (*Rhopalostylis sapida*; Wilmshurst *et al.* 2014) and tree ferns (e.g., *Dicksonia* spp; *Cyathea* spp.). Disturbance by natural fire was rare (Table 2, Fig. 2). This period was recorded at Tawhiti Rahi and both mainland coastal sites. The sediments at Ririwhā did not extend beyond the early Māori settlement period (the corer could not be pushed any deeper) and therefore there is no assessment of the pre-human vegetation at this site. However, there are still traces of many conifer and angiosperm forest taxa present in the early Māori settlement period that are similar to those recorded in the pre-human period of the other sites.

The Māori settlement period (ca. AD 1280) (Wilmshurst *et al.* 2008) is characterized in all the cores covering this period by a sudden decline of tall forest taxa with a corresponding increase in charcoal and seral vegetation (in particular bracken (*Pteridium esculentum*) and grasses (Poaceae)) representing forest clearance for gardens and habitations. With gardening, which often included the practice of blocking waterways for taro (*Colocasia esculenta*) cultivation, wetland species such as raupō (*Typha orientalis*) increased, and on Ririwhā this may have initiated sediment accumulation and the development of a wetland in a small, narrow valley that still exists today (Table 2, Fig. 2). Taro plants were found growing in the swamp where we sampled at Ririwhā, confirming its persistence at this site since at least the 1980s (Matthews 1985).

The European settlement period (from the late 1700s) is characterized by the conversion of remaining lowland forest and scrubland into pasture. This is reflected in all the pollen records by the sudden appearance of exotic taxa such as grasses (Poaceae), pine (Pinaceae), and agricultural weeds such as *Plantago* spp. Within this period we separate two vegetation sub-states: European-modified and European-successional. The European-modified sub-period was characterized by a decline in species present during the Māori period, but a rapid rise in raupō, Poaceae, exotic Pinaceae, and *Plantago*. The European-successional sub-period was unique to Tawhiti Rahi. Although the record from this island also shows decline of taxa dominant during the Māori period, rather than further woody clearance and replacement with grasses

and exotics typical of most coastal regions it shows the rise of and ultimate dominance of the tree pōhutukawa (*Metrosideros excelsa*) together with a diverse range of other angiosperm trees (Wilmshurst *et al.* 2014). A tall native forest canopy recovered on Tawhiti Rahi because burning, gardening and habitation on the island ceased after an inter-tribal massacre in 1823, and a *tapu* (prohibition of, in this case, human habitation) was placed on the island, which allowed it to re-vegetate naturally. Our pollen records indicate that the southern-most sites of Whangaruru and Tawhiti Rahi maintained a greater native forest presence after human arrival than the northern sites (Fig. 2).

Māori Biocultural Restoration Goals for Coastal Ecosystems

Most interviewees from both iwi emphasized a desire to restore coastal ecosystems to states that would deliver future cultural, social, economic, ecological, and ecosystem service benefits. The reinstatement of a customary seabird harvest, primarily of grey-faced petrel chicks, and regaining access to *rongoā* were common 'cultural' motivations for engaging in coastal forest restoration. The harvest of natural resources was considered to be culturally-defining for both iwi and also important in establishing identity and *mana whenua* (rights of the original people of the land) status. In some cases the restoration of single cultural keystone (e.g., grey-faced petrel) or *kaitiaki* species (species of significance that act as cultural sentinels or guides, or guardians of the site, region or people) was considered highly significant. For example, the endemic reptile tuatara (*Sphenodon punctatus*, also known as *kikirawiki* by one Ngātiwai elder), was deemed to still have an important guardianship role. As one participant described:

> Our kaitiaki have been over-run by legislation; and they've been diminished. Developing a revised awareness of our kaitiaki and their roles in guiding our actions and the way we relate to the environment is important. We consider all plant and animal life as senior to the existence of man. Restoration will help facilitate a return to this process. (T.W. Hetaraka 2011)

'Social' motives related to the process of restoration were largely based on opportunities for employment and the passing on of knowledge of the environment. Equally, activities stemming from a restored ecosystem, such as harvesting of natural resources, were also considered fundamental to enhancing family and community inter-relatedness and participation:

> I think being able to harvest muttonbirds is wonderful. I think it's something that our young people have
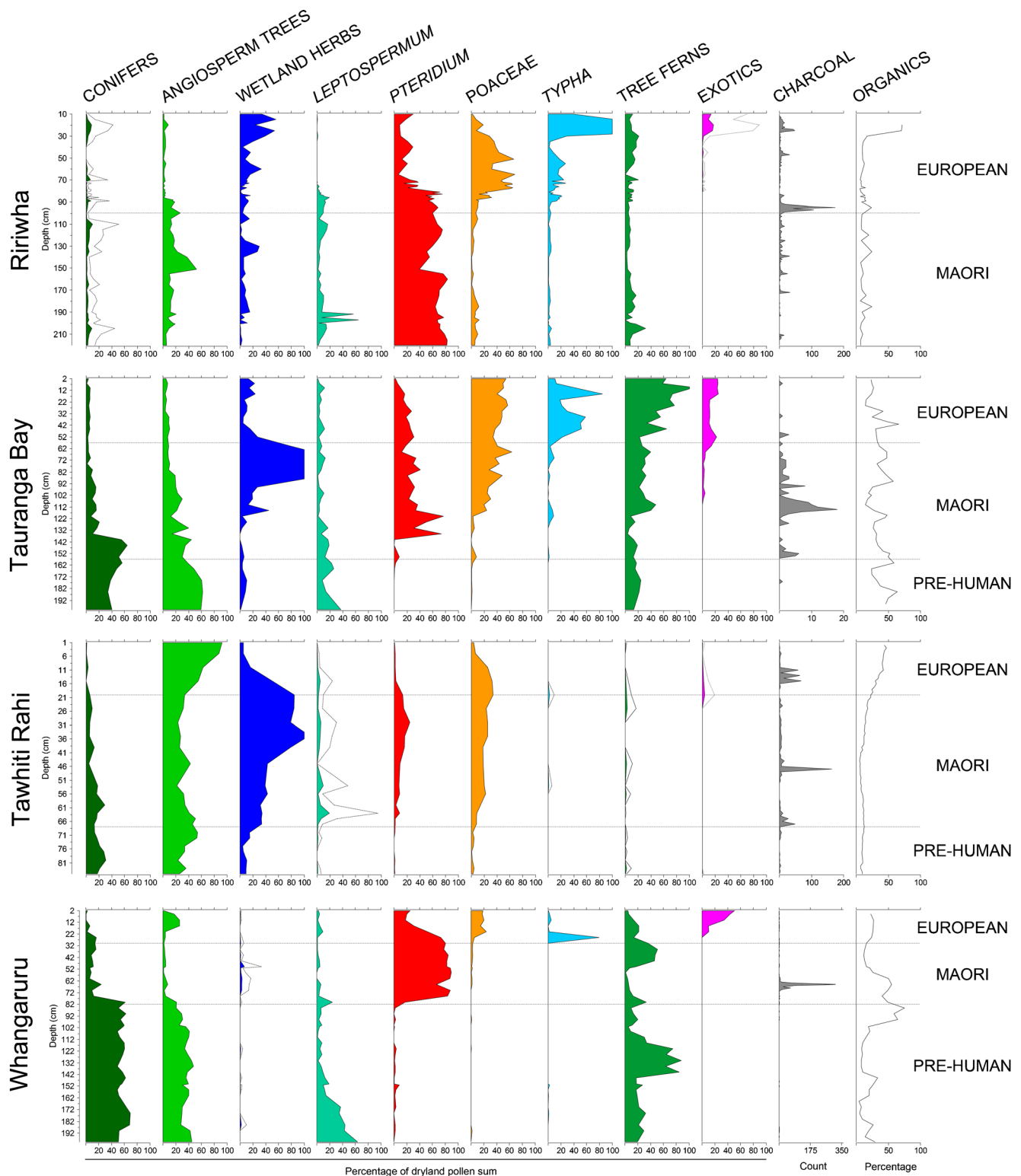
Fig. 2 Pollen signatures for dominant vegetation states during three settlement periods (pre-human, Māori, and European) identified in soil cores from two island (Ririwhā and Tawhiti Rahi) and two coastal mainland sites (Tauranga Bay and Whangaruru Peninsula) in Northland, New Zealand. Nomenclature for pollen taxonomic groups follows Moar *et al*. (2011)

actually missed out. And I think it was also a teaching thing for us as young people, one about sharing and honesty, you know. It was about sharing within the community, since we all had links with one another. Manaakitanga [act of hospitality] and whanaungatanga [act of inter-relatedness] were so strong you know and

that's what we learnt as children from Ririwhā. (M. Wood 2010)

The concept of indigenous agroecology was considered desirable by some Ngātikahu ki Whangaroa participants for 'economic' reasons (e.g., food and revenue from selling sheep products). One interviewee described his preference to have "mutton above and below ground," meaning his ideal coastal ecosystem would have areas that are farmed for sheep and areas of restored native vegetation to support breeding colonies of burrow-nesting grey-faced petrels ("muttonbirds"). Another interviewee, whose ideal coastal ecosystem is "semi-native" rather than "fully native," felt there was a role for agroecology (restoration alongside farming of livestock or gardens for growing kūmara) on Ririwhā. Most interviewees with links to Ririwhā indicated their desire for farming and horticulture as part of their aspirational ecosystem state. They recognized, however, that if farming and biodiversity goals are to be achieved then the compatibility of species and potential interactions need to be considered carefully.

The impact of introduced predators and herbivores on native flora and fauna was the most widely appreciated issue affecting restoration. The interviewees recognized that without a substantial control program for a broad range of pests, restoration of native flora and fauna would be very difficult:

> The biggest thing for me at that time, say about 50 years ago when I first started doing the muttonbirds, was the rat droppings and some of the chicks—by the time you got there they had already been eaten. That was the biggest impact I think was the rat. It was the rat that the Pākehā [Māori term generally used for people of European descent] brought, you know. (B. Sherrington 2010)

There were contrasting perspectives among interviewees about the role and impacts within a coastal forest ecosystem of kiore, which were introduced by Māori settlers during the thirteenth century (Wilmshurst and Higham 2004). Kiore were considered by two Ngātikahu ki Whangaroa interviewees to be responsible for the decline in the burrowing seabirds, tuatara and lizard fauna on Ririwhā. One noted a substantial increase in kiore on Ririwhā in the early 1970s when he returned from military service overseas. Birders would not go out to the island or take children out because of the number of rats. In contrast, another interviewee reported that, before this period, the rats were not considered to be a problem:

> But the old people weren't worried about the rats. I never heard them say, "perhaps we better do something about the rats otherwise …" you know. And even now I don't know whether the rats have an effect? Well I suppose they must have some effect. (D. Rudolph 2011)

One Ngātiwai interviewee reported that he had questioned his elders about the reason for bringing kiore to NZ. After extensive discussions with his elders, the interviewee concluded that his ancestors had been adept at managing island resources and would have transferred kiore deliberately to provide both a future food resource at camping sites and an environmental indicator of ecosystem health, "since the kiore eats the best food for each season." (H. Parata 2011). He also pointed out that the distribution of kiore was to some extent controlled by the "old people" as they were not found everywhere. His reasoning was based on the rat-free status of the Poor Knights Islands, including Tawhiti Rahi, which were formerly occupied by Ngātiwai. Although this island group was settled and modified intensively (for horticulture and with pigs introduced to one of the islands) kiore were never introduced to, or successfully established on, any of these islands. The interviewee suggested, therefore, that his ancestors considered the positive and negative outcomes before introducing kiore to an island ecosystem.

Although interviewees referred to single-species harvests (e.g., grey-faced petrels), they considered that their ecological motives and conservation ethics were more holistic and focused on restoring and protecting the wider ecosystem. There was a common perspective that restoring an individual species was a lower priority than restoring the ecosystem, which would then provide habitat for all species.

> "You protect the habitat and it's the habitat that looks after that species. And so that made a lot of sense to us then and it still makes sense today." (H. Parata 2011)

Recognition of Biophysical Barriers to Restoration

The interviewees recognized biophysical barriers to achieving restoration goals and potential ways to overcome these. Removal of forest cover by fire (Fig. 2), browsing by ungulates (e.g., goats, *Capra hircus*), and the maintenance of grass for sheep grazing over the last 50–100 years have resulted in widespread coastal erosion. Two elders also recognized that in addition to water erosion, removal of topsoil and vegetation was facilitated by strong wind storms striking exposed coastal slopes. Support for this claim was evident by the thick overburden of in-washed clay in our pollen core at Whangaruru Peninsula, which is where the interviewee lived. The current paucity of topsoil at many sites was identified as a significant barrier to the re-establishment of coastal forest ecosystems. These elders also recognized that restoring coastal forests would mitigate coastal soil erosion and improve water quality in the surrounding rivers and near-shore marine environments.

One elder proposed the combined planting of pōhutukawa and harakeke (*Phormium sp.*) to trap and hold remaining topsoils and create a source for humus, since planting harakeke

alone is not enough to mitigate soil erosion and trees such as pōhutukawa are necessary to provide support and structure for new soils. The elder predicted that once a topsoil established these protected sites would become increasingly attractive breeding sites for burrowing seabirds which, through their guano deposition combined with bioturbation from their digging, would deliver marine-derived nutrients to the site. Once the pōhutukawa and harakeke were established, the elder indicated that these sites would also act as nurseries for other native tree and shrub species.
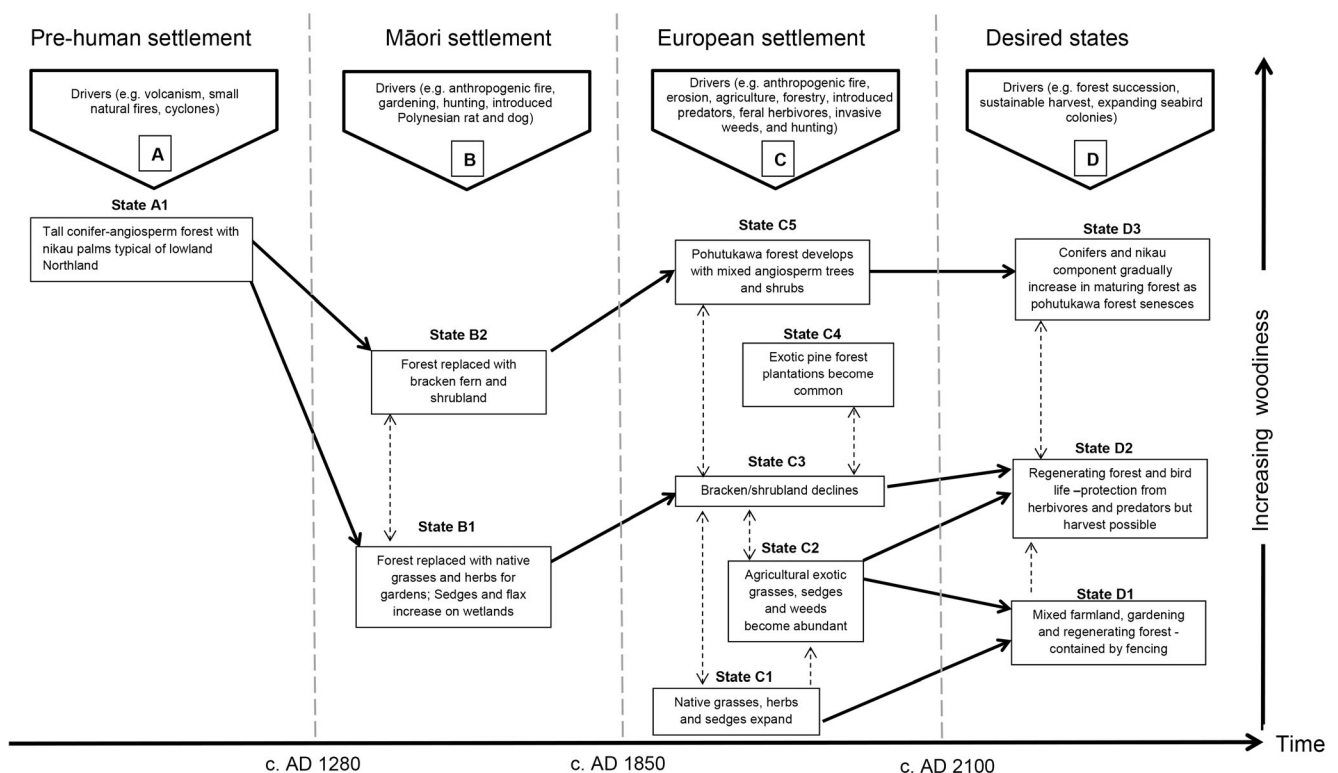
A State-and-Transition Model for Coastal Forest Ecosystems

Our state-and-transition model for the Northland coastal ecosystems (Fig. 3) integrates past trajectories derived from the long-term pollen records with the potential future states desired by the interviewees. It also highlights dominant natural and anthropogenic drivers—such as herbivory, predation, and invasive weeds—that are often required to be managed to achieve desired ecosystem states (Fig. 3, States D1–D3).

Pollen records show that intact native forest currently found on some islands (e.g., Tawhiti Rahi) represents a secondary successional phase (Fig. 3, State C5) and therefore is an unsuitable template restoration goal for other islands where a pre-human forest ecosystem is desired (Wilmshurst et al.

2014). Pre-human forest baselines can only be derived from the palaeoecological record (Fig. 3, State A1). Human arrival in NZ resulted in a major vegetation disturbance (McGlone and Wilmshurst 1999; Perry et al. 2012; Perry et al. 2014) as forests were cleared by fire and vegetation maintained as open grassland/wetlands (Fig. 3, State B1) or bracken/fern shrubland in less horticulturally useful sites (Fig. 3, State B2). During this Māori settlement period, conifers, angiosperm trees and shrubs declined markedly at all our sites except for on Tawhiti Rahi where they are still present (Fig. 2). However, even at Tawhiti Rahi angiosperm composition changed over time from tī kōuka (Cordyline australis) and kawakawa (Macropiper excelsum) dominance during the pre-human and Māori settlement periods to pōhutukawa dominance during the European period (Fig. 3, State C5).

The presence of bracken also increased dramatically at all sites through the Māori settlement period but declined slightly during the European settlement period, which introduced another major vegetation and land-use shift (Fig. 3, State C3). The increase of bracken was likely a deliberate promotion, facilitated by repeated burning of landscapes; its rhizomes (aruhe) had medicinal uses and were a staple food item for Māori well into the early European era (McGlone et al. 2005). The slight decline in bracken spore abundance during the European period can be attributed to further clearance and the introduction of Poaceae (grasses) for grazing livestock at

Fig. 3 Conceptual state-and-transition model of coastal ecosystem and vegetative states for restoration within four settlement periods (pre-human, Māori, European, and aspirational) with related drivers and barriers.

Bold lines indicate transition trajectories and boxes represent alternative system states

some sites (e.g., Ririwhā; Fig. 3, State C2); or the recovery of a secondary forest canopy (e.g., at Whangaruru Peninsula; Fig. 3, State C5). Another significant vegetation change is the increase in wetland taxa, particularly raupō, reflecting changing hydrology following deforestation and increased nutrient in-wash following European farming (Fig. 3, State C1). Synthesis of our long-term vegetation sequences with the local knowledge derived from our interviews allows us to define three potential desired states for coastal forest systems (Fig. 3):

State D1. Mixed regenerating forest, gardening and farming—constrained by fencing to exclude stock from native forests

State D2. Regenerating forest and bird life—requires protection from mammalian herbivores and predators, but traditional harvests a possible long-term outcome

State D3. Conifer and nīkau components gradually increase in maturing forest as pōhutukawa forest senesces and is replaced by taxa common in the pre-human era.

Discussion

Globally, conservation management up until the 1990s was commonly approached through a preservationist lens, predicated on the belief that target "natural" states should exclude people (Craig *et al.* 2000). Since then, the social–ecological systems perspective has challenged this paradigm strongly and places humans within nature, emphasizing reciprocity of environmental and social well-being (e.g., Maffi and Woodley 2010; Sterling *et al.* 2010). In parallel, there has been a shift toward empowerment of local communities and environmental actors to protect, use, and restore ecosystems (Agrawal 2005; Berkes 2007). This promotes the deepening of relationships between people and place rather than dislocation, and that primary attention shifts to strengthen social–ecological links between people and environment.

Placing people closer to the center of ecological restoration inevitably strongly encourages ecological managers and practitioners to confront the need to accommodate widely varying goals and identify ways of achieving them. Our study demonstrates how different knowledge sources might inform and define these decisions and aspirations. However, we recognize that marked differences remain between government, community and individual visions and priorities for restoration (Phipps *et al.* 2011). Factors such as the scale of environmental degradation or modification, cultural perspectives, the ecological realities of restoration (e.g., predator control, changing land use, climate change), national and local politics, financial resources and costs and expert opinion can strongly influence

restoration decision-making (Higgs 2005; Hobbs 2007). Addressing the full range of factors that influence decisions was beyond the scope of this project. However, we demonstrate how two, often neglected, sources of information can be used to inform ecosystem restoration discussions in the early stages of planning.

The goal for this study was to develop a preliminary biocultural restoration paradigm by interfacing local knowledge from Māori communities with prehistorical vegetation records to identify different coastal ecosystem states in northern NZ (Fig. 3, States D1, D2, and D3). A key finding was that currently forested islands, such as Tawhiti Rahi, are not always reliable ecosystem "templates" for re-vegetating other denuded islands (such as Ririwhā) to a pre-human state (Wilmshurst *et al.* 2014). Contrary to previously held beliefs that the forest on Tawhiti Rahi was a climax community (Court 1978; Atkinson 2004), pollen records show that current forest composition is completely different to that before human arrival. It was only after the Ngātiwai occupation prohibition on the Poor Knights Islands that the forest regenerated to a pōhutukawa-dominated forest. In addition, the offshore location of Tawhiti Rahi and the subsequent designation of the islands as a nature reserve have provided a degree of isolation and protection from weed and pest invasion (Atkinson 1986), and from European-era agriculture. These factors have played an important role in allowing the forest on Tawhiti Rahi to succeed rapidly along a natural successional trajectory (Fig. 3, States B2 and C5), although it remains unclear whether it could achieve its pre-human state in the present environment. This contrasts with our other sites, which are more typical of lowland landscapes in NZ, where European arrival heralded intensive agricultural activities, pasture establishment, exotic plantation forestry, the introduction of invasive weeds, and an array of mammalian predators and herbivores. These activities introduced new successional barriers for lowland coastal ecosystems and induced alternative successional trajectories away from the re-establishment of native forest (Fig. 3, States C1–C4). Thus, for example, in order to reverse exotic grassland to a pre-human coastal forest on the currently degraded Ririwhā (Fig. 3, State C2 back to A1), intensive human intervention would be required to overcome the range of drivers now blocking that process (e.g., the presence of exotic kikuyu grass (*Cenchrus clandestinus*), livestock grazing, burning and kiore).

Our pollen records allow us to clearly define a series of past ecosystem states. Similarly, a further suite of palaeoecological proxies may provide insights relevant to cultural conservation issues. For example, faunal bone assemblages can provide information on animal species formerly present (Worthy and Holdaway 2002) or provide information on past harvesting practices (Scofield *et al.* 2003). Stable isotope chemistry can provide landscape-scale information, including identifying the location of former seabird colonies (Hawke and Holdaway

2007; Holdaway *et al.* 2007; Wood and De Pietri 2015), and ancient DNA analyses can provide insights into the history and spread of cultigens and important commensal species (Clarke *et al.* 2006; Thomson *et al.* 2014).

Māori informants identified three basic types of ecosystem that they would like restored in their regions (Fig. 3, States D1, D2, and D3). They recognized that many of the drivers identified in Fig. 3 needed to be overcome to move beyond current system states or facilitate return to past states. They also recognized that interventions such as facilitating the recovery of seabird populations would accelerate the restoration process as well as potentially provide a future customary harvest. Study participants suggested that, with the appropriate level of commitment and interventions, achieving ecosystem goals, such as both mixed land use and restoration to forest (Fig. 3, D1 and D2), was possible within the next 50–100 years. In particular, Ngātikahu ki Whangaroa interviewees perceived a final desired ecosystem state as a mixture of agriculture, horticulture and native coastal forest (Fig. 3, State D1), whereas Ngātiwai participants focused on regeneration of native forest (Fig. 3, State D2). Both groups, however, considered restoration of seabird populations to achieve customary harvest of petrel chicks as a priority for intervention. Likewise, all participants also recognized that restoring pre-human forest states would require intensive human intervention since both the seed source area and abundance of native seed dispersers (e.g., NZ wood pigeon, kukupa, kererū, *Hemiphaga novaeseelandiae*) for native conifers and nīkau palm common in the pre-human era have been reduced significantly through clearance and predation respectively, limiting the natural dispersal of propagules (Kelly *et al.* 2010).

Restoration is commonly influenced by private individual or group preferences or government priorities for individual iconic, rare, or threatened species (Restani and Marzluff 2002; Bell 2003; Campbell-Hunt *et al.* 2010). In contrast, indigenous visions and goals for restoration can vary considerably and drive decisions in quite different directions (Aronson *et al.* 2006; Phipps *et al.* 2011). For example, the restoration of plants and animals for future harvesting was an important driver for Māori participants to contribute and participate in restoration interventions. In particular, cultural keystone species were important in desired ecosystem states. Tī kōuka and kawakawa are typical seral species, and were also widely used by Māori for food, fiber and medicinal purposes (Riley 1994; Simpson 2000). It is likely that these species persisted on Tawhiti Rahi throughout the Māori period for these reasons, and remain highly desired within ecosystems today. They are significant because they define and form the context for a culture and reconnect communities to ancestors, tribal guardians, and the different levels of the spiritual and natural worlds (Garibaldi and Turner 2004; Lyver *et al.* 2009).

The Māori communities were also interested in ecosystem goals that fulfilled a range of conservation and livelihood needs and, accordingly, a range of ecosystem elements were included in their visions for restoration. Agricultural and horticultural species were perceived as useful components providing people with a source of food and potential revenue, which are important considerations in the lower socioeconomic communities of northern NZ. The spiritual, nutritional and indicator roles played by some species, such as kiore, in coastal forest ecosystems can cause cross-cultural conflict (Simberloff *et al.* 2013). For example, some elders within the Ngātiwai community valued having kiore within some coastal ecosystems (Phipps *et al.* 2011), whereas frequent reference to them in the science-based restoration plans (e.g., Towns *et al.* 2003) highlighted them as threats to biodiversity that require eradication. Cultural differences may also arise when restorationists seek to replace the ecological role played by an extinct species by introducing a taxonomically-close substitute (Griffiths *et al.* 2010). In such cases, little consideration is given to the role of the extinct species in the cosmology of local indigenous people, and whether the substitute species would fulfill their spiritual, genealogical, or food requirements. Adding to this Māori also emphasized the value of cultural stewardship and future customary resource use as goals in the restoration process, while non-Māori environmental managers were more likely to stress the importance of restoring ecological integrity (Phipps *et al.* 2011).

Synthesis of Local Knowledge with Palaeo-pollen Evidence to Achieve Desired Ecosystem States

Our over-arching aim of this study was to present evidence from local and scientific knowledge systems that informed community restoration goals. While synthesis and interpretation of the two knowledge systems was presented in our state-and-transition model of coastal ecosystem restoration, we wished to give Māori practitioners the facility to use one or both knowledge systems based on the perceived strengths of each and as they deem culturally and environmentally appropriate.

Local knowledge identified ecosystem pressures (such as invasive weeds, herbivores and predators) that inhibit restoration with recovery thresholds that depend, in part, on the size of the area to be restored and the probability of reinvasion. It is becoming increasingly feasible to remove mammalian predators and herbivores from larger areas, although reinvasion remains a critical potential threat (Clout and Veitch 2002; Scofield *et al.* 2011; Young *et al.* 2013). For example, the increasing dominance of invasive plants in coastal regions of northern mainland NZ means that natural successional trajectories such as that on Tawhiti Rahi over the last 160 years would likely lead to an entirely different stable state if forest was removed from a near-shore island today. Therefore, intensive active restorative management would be required at mainland sites to achieve aspirational ecosystem states. This

heightens the need for detailed knowledge about the original state and any potential restoration thresholds. This is the situation on Ririwhā, where the spread of highly competitive and dense exotic kikuyu grass and the time elapsed since the removal of native forest vegetation means that initiating a natural regeneration trajectory is now impossible without significant intervention. Local knowledge and experience informed us that a structured re-planting program on Ririwhā would fail without intensive control of kikuyu grass in the primary successional phases to prevent smothering. As a consequence, Ngātikahu ki Whangaroa have been caught in a cycle of using two anthropogenic drivers on Ririwhā (sheep and fire) in order to control another (kikuyu grass). Fire is very unlikely to control kikuyu grass, since this species promotes a grass/fire cycle (D'Antonio and Vitousek 1992).

A number of participants identified the loss of topsoil as one of the major barriers to future restoration efforts. Most of our soil cores showed an increase of mineral input during the human era as a result of erosion following loss of dense vegetation cover (Fig. 2). Therefore, soils are threatened by biodiversity loss while the restoration of biodiversity is largely dependent on the quantity and quality of soils. Once high-grade topsoil is lost from an ecosystem it becomes very difficult to replace. Topsoils, on average, accumulate at a rate of about 20 mm every 500 years (Müller and Cummins 2009), although maturation rate depends largely on local climate. Topsoils mature as organic matter is assimilated into the soil and nutrients are released from minerals to the soil solution where they can be utilized by plants and trees (Molloy 1998). Pōhutukawa and harakeke were suggested by participants as ideal vegetation in northern coastal environments for creating a humus layer and stimulating soil creation. In addition, interviewees recognized pōhutukawa and harakeke would generate ideal habitat for burrowing petrel populations, which are, in turn, important ecological engineers providing marine nutrient subsidies and aerating soils with their burrowing activities (Fukami et al. 2006; Whitehead et al. 2014). Interviewees were also able to identify past locations of burrowing petrel colonies, including estimates of numbers and species of birds occupying those sites. This is valuable information for predicting potential rates of ecosystem restoration if efforts were made to return a particular petrel species, or combination of species, to those sites.

Mitigation of the range of barriers to achieving ecosystem goals takes varying amounts of time and investment. Natural recovery assisted by intervention will be quicker and easier to achieve for some barriers (e.g., predator removal) than others (e.g., topsoil accumulation). Therefore, the difficult decision facing many practitioners is when to reintroduce species back into what may be sub-optimal habitat, and in what order they should be reintroduced (Armstrong and

Seddon 2008; Seddon et al. 2009). Many restoration initiatives around NZ involving burrowing petrels occur in the absence of a coastal forest, yet most remaining large petrel colonies occur under canopies. An understanding of species assemblages such as provided in this study, and also how those ecosystems functioned, can help inform these decisions.

Conclusion

Globally, there is an increasing shift toward restoring entire ecological communities or ecosystems. Our study demonstrates how two different sources of qualitative and quantitative ecosystem information can be used to support Māori, government, community manager and practitioner planning efforts in defining biocultural restoration goals for coastal forests, but can also facilitate the reconnection of communities to the environment. We emphasize that palaeoecological records provide a reliable way of establishing pre-human vegetation baselines, while restoration visions of local indigenous communities are likely to include ecosystems that encompass humans and their activities (such as customary use or agroecology) as integral elements, as well as pre-human forest states. Practitioners should not rely solely on existing forest ecosystems as desired states for restoration to pre-human states, as they may be highly modified despite being dominated by native forest taxa. Our local knowledge sources recognized that natural succession back to a pre-human settlement state in highly degraded ecosystems is unlikely without intensive human intervention. New drivers and barriers (e.g., introduced herbivores and predators, invasive weeds), which influence factors such as propagule sources and the abundances and distributions of dispersers, heavily influence the direction of successional trajectories and must be considered at the outset of restoration initiatives. Local knowledge can inform on many of these challenges and should therefore be consulted early in the planning stages. The presence of both native and introduced species in a restored ecosystem desired by the Māori communities means that consideration of novel stable states, and innovative approaches to achieve those states, are required.

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