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Ecological and social-ecological memory are central to landscape restoration

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Abstract:	Despite living in an era of big data and associated methodological advances, we also live in a world of environmental amnesia. As ecosystems change, we may lose ecological memory, such as physical legacies and adaptations shaped by past environments, and social-ecological memory, in the form of lost knowledge, beliefs and practices related to those environments. Restoration efforts should seek to learn effectively from the past, carefully integrating appropriate forms of ecological and social-ecological memory using a pluralistic approach combining different knowledge sources, perspectives and data that span multiple scales. This pluralism may challenge top-down notions of restoration and requires it to be seen as a (re)generative process encompassing natural and social capital and well-being.

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Cover Letter

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The Editor-in-Chief
Trends in Ecology & Evolution

Re: Submission of Ecological and social-ecological memory are central to landscape restoration to *Trends in Ecology & Evolution*

Please find enclosed a manuscript entitled Ecological and social-ecological memory are central to landscape restoration to *Trends in Ecology & Evolution*. In our opinion piece, we develop an argument that ecological and social-ecological memory are critical components of ecosystem restoration. We illustrate these points using two contrasting case studies: (i) deforestation by fire in New Zealand since human settlement and aspirations for restoration, and (ii) changes in alpine meadow and steppe on the Qinghai-Tibetan plateau under intensifying grazing. The structure of our opinion piece is:

- we start by introducing the idea of 'memory' and how it is intimately related to issues of path-dependence and scale-dependence
- define ecological and social-ecological memory, distinguishing between internal and external sources of memory
- show how scale, scaling and memory are intertwined and how memory can be integrated into existing scaling frameworks
- highlight how ecological and social-ecological memory may confer resilience on ecosystems and how erosion and loss of these memories can change ecosystem trajectories
- show how ecological restoration often, even if implicitly, seeks to return memory to ecosystems and what the consequences of failing to do this might be
- illustrate the points above using two contrasting case-studies where ecological and social-ecological memory have been eroded or lost from ecosystems, and how reinstating this memory will be fundamental to their successful management and restoration

We believe that our synthesis is novel in that it:

- explicitly integrates ecological and social-ecological memory, including the importance of traditional environmental knowledge and contested and counter-memories
- demonstrates how considering (whether remembering or forgetting) ecological and social-ecological memory is fundamental for successful ecological restoration and requires integrating data across different scales
- goes beyond considering memory in the context of disturbance (the focus of much previous work) and draws on concepts of memory from other disciplines (e.g. geomorphology, hydrology)

I confirm that the enclosed work has not been published or accepted for publication, nor is it under consideration for publication elsewhere; all authors named on this manuscript have read and approved it for submission.

We look forward to hearing from you in due course.

Best regards,

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Ecological and social-ecological memory are central to landscape restoration

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Highlights

- Ecological memory and social-ecological memory are deeply intertwined and are argued to be important components of restoration as they support resilience. Ecological memory comprises the entities persisting from the past (e.g. woody debris) and information legacies (adaptations or behaviours), and social-ecological memory comprises the institutions, knowledge, beliefs and practices developed by people that relate them to the environment.
- While memory is important for restoration it is not uniformly 'good'. Thus, it is not always the case that reinstating memory is desirable. Ill-sighted management interventions have left undesirable residuals and regimes, and social-ecological

memory may be contested and maladaptive; forgetting may be as important as remembering.

- What is desirable in terms of restoration will always have a subjective element. Likewise, social-ecological memory is likely to be contested and reflect specific positions of power. There is an important place for counter-memory in developing restoration programs.
- There is a risk that efforts to integrate ecological and social-ecological memory into restoration fail to recognise its inherent dynamism, and so appeal to some pre-determined condition. Just as memory is dynamic, restoration that draws on it needs to be proactive and precautionary to be able to respond to emergent dynamics, contingencies and associated uncertainties.

Glossary

- The term *biocultural* is used broadly to express the inextricable links between many natural and human (cultural) systems and, in particular, their diversity [1]
- *Ecological memory* is the persistence of ecological structures and patterns that affect subsequent ecosystem dynamics. We distinguish between residuals (the physical entities left by past processes) and information legacies (long-term adaptations to the environment) [2].
- Following [3], *knowledge-practice-belief complexes* are the collective outcome of human knowledge of the environments they inhabit (learned, observed and experienced), the way humans interact with their environments ('practice') and the beliefs they develop about their relationship with the environment. These complexes are dynamic and represent the outcome of repeated human-environment interactions.
- *Resilience*, in an ecological sense, is the ability of a system to experience perturbation without shifting to a new state [4].

- *Social-ecological memory* is the knowledge accumulated about an environmental system and the related behaviours and beliefs, that develop through human-environment interaction.
- *Space-time domains* are the characteristic scales at which ecological and social patterns are evident, at which the processes generating those patterns are strongest, and at which these patterns need to be sampled.

Abstract

Despite living in an era of big data and associated methodological advances, we also live in a world of environmental amnesia. As ecosystems change, we may lose ecological memory, such as physical legacies and adaptations shaped by past environments, and social-ecological memory, in the form of lost knowledge, beliefs and practices related to those environments. Restoration efforts should seek to learn effectively from the past, carefully integrating appropriate forms of ecological and social-ecological memory using a pluralistic approach combining different knowledge sources, perspectives and data that span multiple scales. This pluralism may challenge top-down notions of restoration and requires it to be seen as a (re)generative process encompassing natural and social capital and well-being.

Keywords

disturbance; ecological memory; resilience; social-ecological memory; traditional environmental knowledge

Introduction

Events in the past influence contemporary ecosystems through the legacies they leave [5,6]. Here, we consider the cross-scale dynamics inherent to ecological memory and social-ecological memory (SEM) drawing on the ecological and geomorphological

77 literature; and illustrate, using two case-studies, the necessity to consider ecological and
78 social-ecological memory in environmental restoration. While we emphasise the central
79 role of ecological and social-ecological memory in restoration, memory is "not an umixed
80 good" [7, p. 111]; it may guide what *not* to do as much as help identify interventions.
81 Likewise, any discussion of restoration must consider the (potentially dynamic) targets for
82 restoration, how they are developed, and how their success is measured [8]. Proactive and
83 precautionary environmental interventions need to be selectively informed by actions that
84 work and by lessons learnt, and move beyond bad decisions, regimes and their ensuing
85 legacies; ecological and social-ecological memory are fundamental to this effort.

86

87 Types and scales of memory: ecological and social-ecological

88 What is ecological 'memory?'

89 Ecologists use 'memory' to describe the persistence of ecological structures and patterns
90 that affect subsequent ecosystem dynamics [9–11] (Fig. 1). Analogous concepts have been
91 developed in other natural sciences. For example, Schumm & Lichty [12] argued that a
92 scale-dependent and historical perspective is crucial for understanding landscape
93 evolution ("the neglect of time leads to confusion and needless controversy", p. 111).
94 Likewise, Brierley [13] described a geomorphic 'landscape memory', discriminating
95 between tectonic, climatic and anthropogenic memory, with the latter the signature of
96 human activities on the landscape. From an environmental humanities perspective, Buell
97 [7, p. 96] defines environmental memory as "the sense (whether or not conscious, whether
98 or not accurate, whether or not shared) of environments as lived experience in the fourth
99 dimension". Beyond definitions, efforts have been made to measure ecological memory by
100 considering temporal autocorrelation and lags in community states [14,15]. Ogle et al. [15]
101 decompose memory into length (how long does memory persist?), temporal pattern (what
102 is the variability and lag in memory effects?) and strength (how important is memory for
103 system dynamics?); in geomorphology, conceptually similar ideas were presented by
104 Brunsden & Thornes [16]. Operationally, the strength and persistence of ecological

memory can be quantified as the improvement in a model's predictive performance when it includes past (antecedent) conditions and over what duration this effect is observed [see 14,17 for contrasting examples].

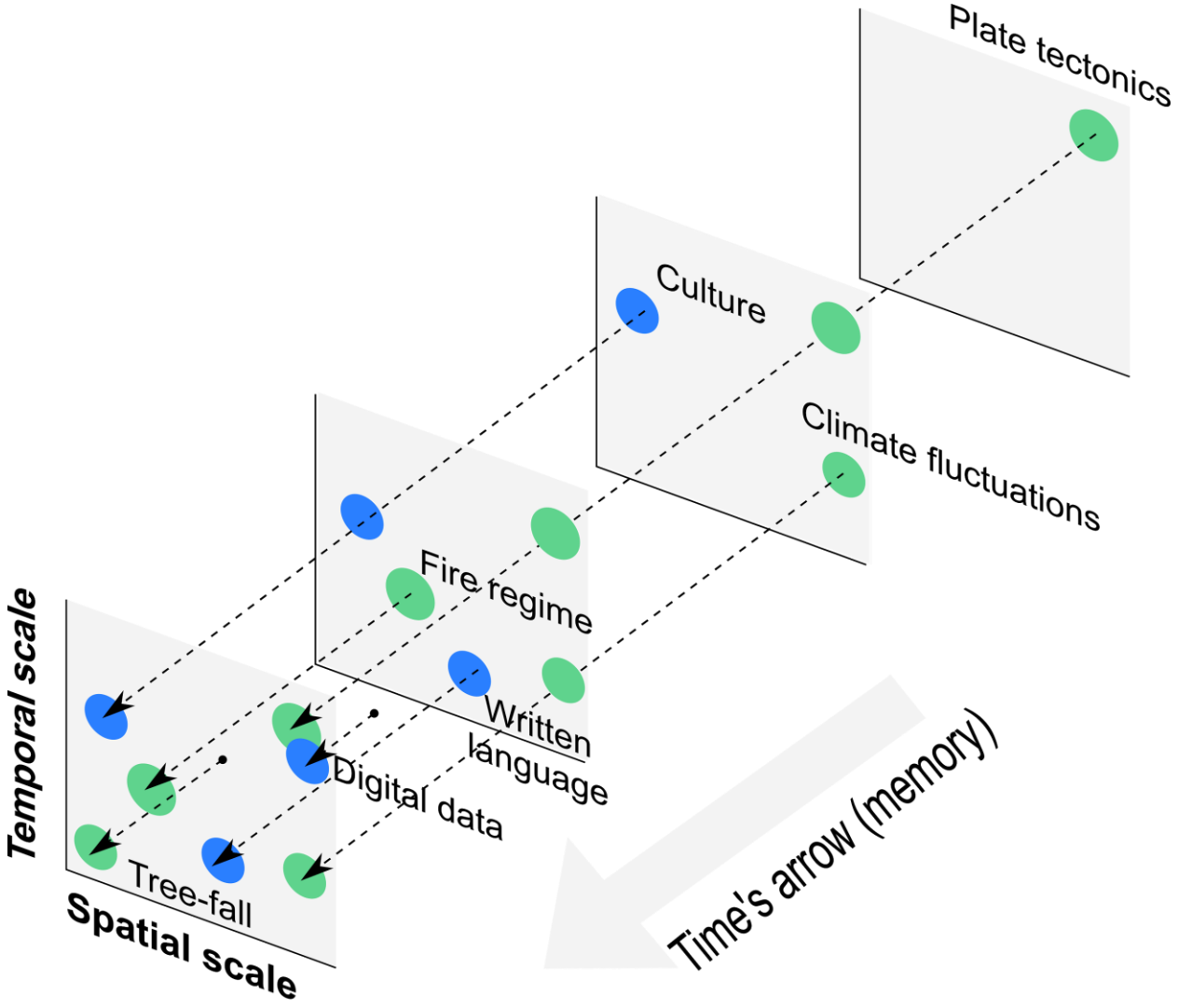

Figure 1: Memory as a third dimension on space-time domain plots; here the 'memory' (z) axis has an implied log-scale. Rather than just being constant or linearly fading, the strength of memory may vary over; the idea of time's arrow is discussed by Gould [18].

Ecological memory is fundamental to ecosystem resilience; the ability of a system to experience perturbation without shifting to a new state [4,19,20]. Ecological memory comprises material residuals and information legacies [2]. Residuals are physical structures that persist after perturbation and influence an ecosystem's subsequent trajectory, whereas information legacies are the long-term genetic and behavioural adaptations to environmental conditions; combined, these provide an ecosystem's adaptive capacity. If the environment changes such that material residuals are removed or information legacies become misaligned with current conditions, ecosystems can change abruptly and unpredictably [2]. Following environmental state changes, the ecological memory of the system will also alter, even if there are non-linear lags in the formation of the new memory, and may hold the system in its new state (e.g., the material legacies of invasive species as in propagule banks or nutrients in culturally eutrophied lakes). In short, and as with memory, resilience is not uniformly desirable [21].

Ecological and social-ecological systems have internal and external memory ([22]; Fig. 2). Internal memory is held within a given system (e.g., the residuals after disturbance or place-based knowledge or practices), whereas external memory comes from sources outside the ecosystem (e.g., via propagule dispersal or knowledge diffusion). This distinction emphasises that memory is more than just entities 'left behind' after an event. External memory can involve flows from adjacent or non-adjacent ecosystems; for example, seed dispersal by animals moving seeds or biogeochemicals over long distances [23,24]; these cross-system interactions can challenge management frameworks limited to specific locations or scales.

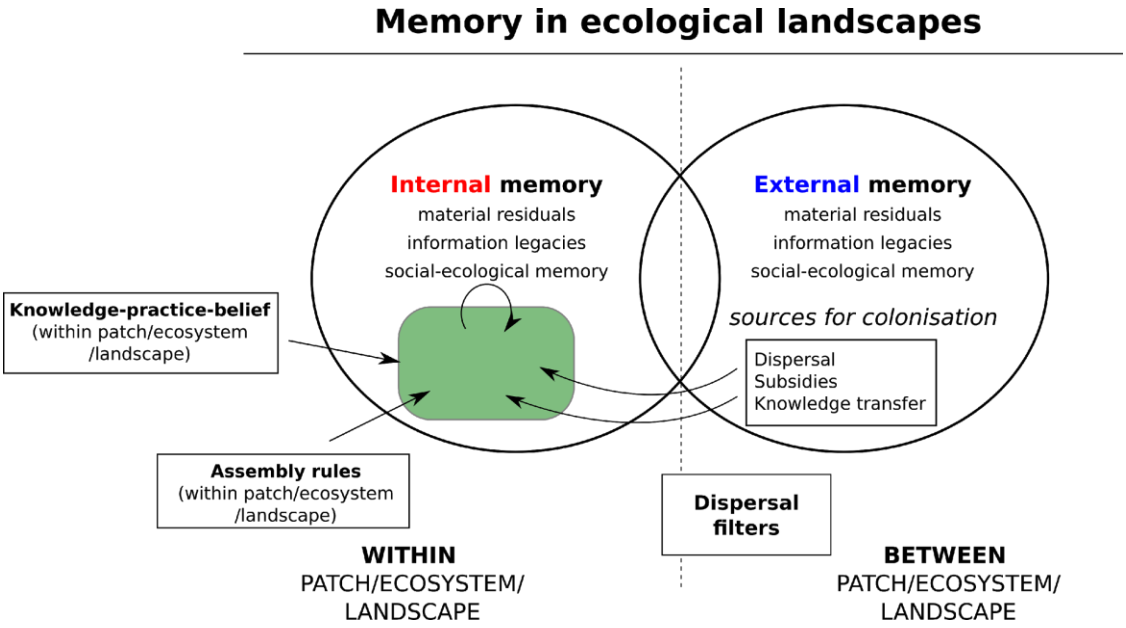

Figure 2: The memory of ecological landscapes integrates ecological and social-ecological memory and integrates internal (within patch/ecosystem/landscape) and external (from neighbouring or disjunct patches/ecosystems/landscapes). The green rectangle is an area that is responding to a perturbation; modified from [22].

What is social-ecological memory?

Buell [7] describes four forms of environmental memory: (i) biogeological memory, (ii) individual lifelines, and narratives of (iii) communities and (iv) nations. These span the activities of humans against a backdrop of long-term environmental change, individual identity as shaped through connection with places, and the collective memory of interdependencies between people and the environment. Social-ecological memory (SEM) is the "accumulated experience and history of the system (both ecological and social), which provide the basis for self-organisation" [25 p. 96]; this definition encompasses not only individuals and communities but also institutions and governance arrangements. It is, therefore, inherently linked to resilience. This memory can profoundly influence ecosystem change and how humans respond to it – ecological memory and SEM are dynamically intertwined [26]. SEM has internal (knowledge transfer and learning within communities)

and external (diffusion of knowledge from other contexts) components – even if the latter has often swamped the former as local cultures have become homogenised [27]. It is worth noting that SEM is distinct from social memory, which is the adaptive capacity of social structures [28]. While social memory may require or reinforce ecological memory, they can also be independent.

Knowledge-practice-belief complexes are an important dimension of SEM [3,29]. These perspectives and practices represent an adaptive and collective response to the environments and societies that people inhabit [3,30,31] and may be eroded or lost as ecosystems move beyond historical conditions or people are disconnected or dispossessed from the environment [27,32,33]. As conditions change, SEM may reinforce undesirable or maladaptive behaviours or hinder adaptation [34, 38]. Likewise, a group's memory may be heterogeneous and contested , and any discussion of SEM must navigate potentially difficult and troubling questions about its formation and persistence [7,34]. In any social group, the dominant story (or memory) is likely to reflect embedded power structures [25,34]. Thus, 'counter-memory' has an important role in SEM, especially regarding resource competition and acquisition or dispossession, and can help to foster more proactive ecological interventions.

Institutional memory as the imprint of past management actions is another element of SEM. For example, 'command and control' environmental programmes can lead to path-dependent dynamics; Beattie & Morgan [35] describe how colonial perspectives were imposed upon river management across the British 'empire'. More generally, a pervasive aspect of colonialism has been the imposition of an anthropocentric perspective that natural environments are resources for (extractive) use [36], which erodes local knowledge-practice-belief complexes and has framed environmental management. Related is the collective and individual memory of the condition (state) of the environments that humans interact with. This memory frames what we perceive as 'normal', and underpins shifting baseline syndromes [37]. Shifting baselines not only make it difficult to set management targets; they can also be profoundly psychologically troubling for those

184 experiencing them [38]. Related are the concepts of ecological amnesia [39] and
185 environmental generational amnesia [40], which emerge as humans are decoupled from
186 natural systems.

187

188 Collective practice, institutional memory, and individual perception and memory of the
189 environment interact; thus, as baselines shift so will knowledge and transmission of
190 collective practices [27]. While SEM provides adaptive capacity, it can be deeply politicised.
191 For example, shifting baselines can be used to justify an institutional failure to respond
192 adequately to degradation [41], or can be incorporated into restoration agendas as
193 assertions (perceptions) of what is 'pristine' [42].

194

195 The costs of gaining, losing and rescaling ecological memory and social-
196 ecological memory

197 Delcourt *et al*. [43] articulated the idea of space-time domains, which map patterns (system
198 responses) at a given scale to the processes generating them; Clark [44] extended this
199 framework to encompass social and economic structures and processes. How does
200 memory fit into these space-time domains? A fundamental scale-based measure of memory
201 is its temporal persistence [15], which is either the length of time an object or its effect
202 persists in a system. For SEM, scaling may be captured by the temporal extents over which
203 the past influences contemporary practices and behaviours. As Fig. 1 suggests, a gradient
204 from 'fast-small' processes to 'slow-large' processes (e.g., treefall vs. climate cycles) can be
205 mapped to ecosystem responses to the environment (e.g., competition vs. evolution). A
206 challenge in integrating memory into this framework is that it does not necessarily align
207 with the fast-small, slow-large gradient [45]. Some localised and rapid processes can
208 persist for long periods (e.g., burrowing activities, some management practices); large-slow
209 processes may be integrated over an individual's lifetime and so be effectively undetectable
210 (e.g., the effects of long-term change on short-lived organisms). Likewise, feedbacks in
211 landscape dynamics challenge scaling memory as they may reverberate or strengthen

212 through time [46]. A final challenge is that the creation and loss of memory is not
213 symmetric: ecological and social-ecological memory can be rapidly eroded or lost (in just
214 one event) but take much longer to develop.

215

216 Many of the most pervasive effects of humans on ecological systems involve rescaling in
217 space and time [5]. For example, fragmentation effectively reduces a landscape's size so
218 increasing disturbed area in a relative sense, representing a rescaling in space; similarly,
219 anthropogenic climate change is a rescaling of the rate of temporal change. Such rescalings
220 shift the location of the processes and responses depicted in space-time domains and/or
221 change the area they cover in space-time, leading to the questions of which patterns and
222 processes can be warped and which cannot? Will ecological and social-ecological memory
223 be able to track such warping? Can restoration help re-align these rescalings?

224

225 Considerable attention has been paid to how changes in multiple and interacting
226 disturbance regimes will influence the persistence and strength of ecological memory [2].
227 These changes in memory, in turn, mean that the information legacies in a system may
228 become misaligned with current conditions. However, even if less well articulated,
229 rescaling of memory is not limited to changes in disturbance regimes. For example, human
230 activities have altered the rate of flow of biogeochemicals through the earth system [47],
231 converting sources into sinks and *vice versa* with potentially long-lasting legacies [48,49].
232 Likewise, humans are creating novel ecological memory by introducing new physical
233 (e.g., micro-plastics) and biological entities (e.g., GMOs) into the environment –the
234 persistence and strength of these 'novel memories' may be difficult to ascertain.

235

236 The four types of environmental memory described by Buell [7]—biogeological memory,
237 individual lifelines and community and national narratives—span a range of scales from
238 the individual's experience to long-term geological context in which human activity occurs.
239 As with ecological memory, SEM may become misaligned with prevailing social and

environmental conditions. Such misalignments may be due to, or reinforced by, active displacement or disempowerment of indigenous people, local communities, and other stakeholders. Tang and Gavin [32] outlined threats to traditional ecological knowledge and practice: loss of transmission pathways, changes in livelihood practices, changes in traditional beliefs and religion, changes in the natural environment, loss of tradition rights and institutions. These threats are not mutually exclusive. As people are disconnected and dispossessed from their environments, SEM may be increasingly difficult to reinstate [27]. As SEM disappears, any community's ability to respond to rapid change will dwindle [31], with a concurrent risk of undesirable transitions and associated hysteresis (whether ecological or social-ecological).

Restoring ecological memory and social-ecological memory to landscapes and ecosystems

Ecological memory and SEM profoundly shape what environmental restoration can realistically achieve. Contingency and emergent social-ecological dynamics and conditions highlight the imperative for flexible place-based management that recognises cross-scalar relationships [50]. The loss of ecological and social-ecological memory may irreversibly reduce resilience and thus challenge the persistence of restored ecosystems. However, although conceptual understanding of resilience in the face of disturbance is reasonably well developed, applying these concepts has proven challenging [51,52]. Hence, a key question is 'how can we restore or increase *desirable* ecological and social-ecological memory?', remembering that desirable is inherently subjective.

Schweiger et al. [24] identify four characteristics of ecosystems relevant to memory and restoration, which can be extended to include SEM:

1. time since loss of key knowledge, entities or processes (e.g., keystone and/or engineer species, specific practices)
2. rate of turnover of energy, matter and information after perturbation or disruption

3. the strength of remaining ecological and/or social interactions, and,
4. the nature of surrounding and connected ecosystems and social collectives

These characteristics determine the remnant memory in the system after perturbation, whether ecological or social-ecological, and hence inform potential restoration interventions. Identifying the nature of what has been lost and the characteristics described by Schweiger et al. [24] will help to identify successful and resilient intervention pathways. For example, if the time since memory loss is short and turnover rate slow then there is likely to be more residual memory than in the opposite case. The greater the loss of a system's internal memory, the more important its external memory becomes. Not all species and processes will have the same value for ecological or social-ecological memory, and so the most important need to be identified, especially if they are important for both. For example, in some ecosystems large trees are both ecologically (e.g., C sequestration, habitat provision) and culturally (e.g., spiritual significance, provisioning services) important, and hence may be key for retaining or restoring memory [53].

Ecological restoration will frequently explicitly require considering social-ecological memory alongside ecological memory. This consideration may be learning from past measures and practices and rejecting them; or it may be in fostering memory to counter environmental generational amnesia given its roots in childhood experience [40]. As with ecological memory, the extent of the erosion of social-ecological memory will vary with the length of time that a group has been displaced or disconnected (e.g. via the loss of key cultural and ecological entities or processes) from their environment and the rate, magnitude and nature of environmental change. Reinstating and nurturing social-ecological resilience and associated knowledge-practice-belief complexes will require careful attention to collaboration (horizontal and vertical) and learning (drawing on social-ecological memory and experience) [25]. As with ecological memory, considerations of social-ecological memory must acknowledge its inherent dynamism and avoid framing it narrowly as a return to some arbitrary, predetermined past condition [7,27] and accept there may be multiple baseline states to select from [54].

Concluding remarks

Although memory, whether ecological or social, conveys resilience on social-ecological systems, we are seeing its widespread erosion and loss of ecological and social-ecological memory in many systems. Reversing this loss will require integrating data and knowledge across diverse domains and epistemologies [69] and translating it in useful ways to diverse stakeholders. However, as with resilience, memory is not uniformly positive; reflecting on that past must involve remembering failures and rejecting the practices that led to them. Restoration practitioners must (i) acknowledge the loss of ecological and social-ecological memory and (ii) seek to foster knowledge and practices that engender suitable SEM, even if they are potentially disruptive (such as counter-memory). Of course, this is not easy but concepts such as the identification and conservation of biocultural refugia – the places in landscapes where various forms of ecological and social memory intersect [55] – offer potential solutions. If it is ultimately a human endeavour, the very language of restoration as a regenerative socio-cultural activity becomes crucial; successful restoration can no longer be measured in purely ecological terms but as we re-fashion memory this should offer a renewed basis for identity, belonging and well-being.

Outstanding questions

- The conceptualisation of ecological memory as comprising residuals and information legacy has been most frequently applied in the context of disturbance ecology. How applicable are these ideas to other forms of ecological and social-ecological change? And at what spatial and temporal scales?
- How best can we balance the need to reinstate ecological and social-ecology memory with the need to erase some memories of the past (legacies of inappropriate management interventions, cultural dispossession from the environment)? How do we identify these components?
- What is the place of social, as opposed to, social-ecological memory in environmental restoration?

- How can counter-memory and counter-narratives contribute to efforts to restore environmental systems?

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Box 1 - The Qinghai-Tibetan Plateau

The adoption of grazing-adapted ecosystems in the Sanjiangyuan atop the Qinghai-Tibet Plateau (QTP) reflects a persistent long-term social-ecological memory imprinted by land-use change from forest around 8000 years ago [56]. Long-standing socio-cultural traits and adaptive capacity associated with low human populations and stocking rates maintained sustainable and productive grasslands. These relations established over thousands of years were threatened by government changes to land-use policy that altered land tenure arrangements and increased yak (*Bos grunniens*) numbers [57]. Viewed alongside climate change and other disruptions, grassland degradation ensued [cf 58,59]. In extreme instances, increases in the area of bare ground presented additional opportunities for enhanced burrowing activities by pika and other mammals, prompting questions as to their ecological role "ecosystem engineer or pest" [60,61]? A positive feedback amplified the emergence of severely degraded grassland (heitutan), with limited prospects for recovery [62]. Recent environmental protection programmes have sought to reverse this trajectory, with large-scale grassland and wetland regeneration through a range of measures including land use changes (limits on stocking rates) and regeneration. Other initiatives, such as pika eradication programmes (fencing, poisoning) and resettlement (ecological migrant initiatives that re-house traditional herders in permanent townships), however, have arguably contributed to further erosion of ecological memory.

Social-ecological and institutional memory play out in different ways and at different scales in this landscape – from vegetation-soil interactions around pika burrows (sub-m^2), to region-wide stocking rate and revegetation initiatives (> 1×10^3 km^2). Choices made and policies adopted have profound implications for the future of these landscapes. If left alone, forest would likely regenerate over time, with heightened prospects in light of changing climatic conditions. However, this outcome is unlikely as maintenance of grazing adapted ecosystems is the preferred 'state' and social-ecological lifestyle preference for the area. However, if human population density and stocking rates increase, traditional lifestyle values are threatened or may disappear, with associated loss of social-ecological memory.

Alternatively, if land is abandoned or stocking rates are too low, traditional meadows are lost, with loss of ecological memory. Finding an appropriate balance is the key driver of contemporary environmental protection policies on the QTP, and will require recognising the deeply reciprocal nature of ecological memory and social-ecological memory in these vast landscapes [63].

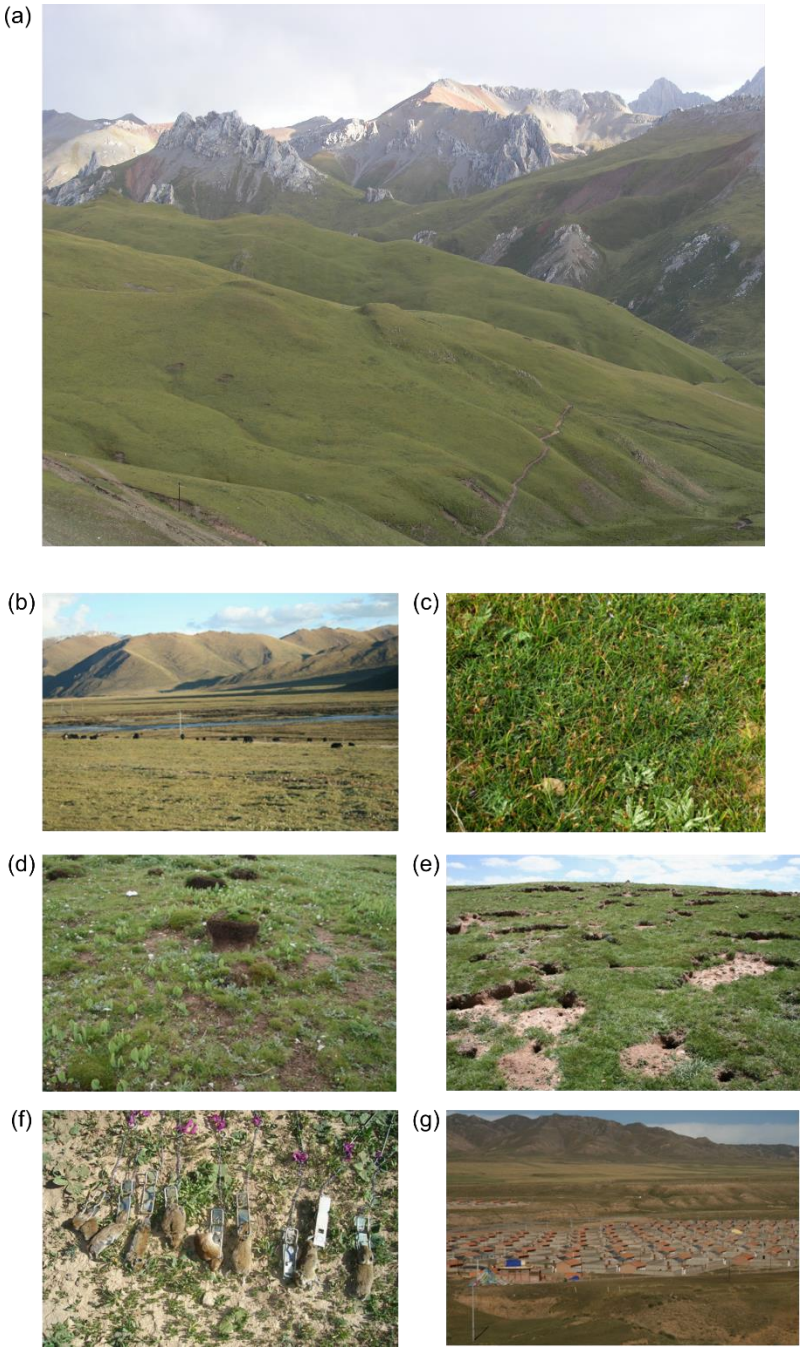

Figure B1 – The multi-facetted nature of memory and its formation on vast alpine landscapes (a) of the Qinghai-Tibetan Plateau. (b) Yak browsing at low intensity in alpine meadow, (c) intact cushion meadon dominated by *Kobresia* spp., (d and e) degraded meadow (Heitutan) with eroded pedestals and bare ground, (f) efforts to 'control' the assumed cause of the degradation, the ecosystem engineer the Platea Pika (*Ochotona curzoniae*) and (g) a resettlement village.

Box 2 - New Zealand forests, shrublands and rivers

When humans first settled Aotearoa-New Zealand in the mid-13th century [64] more than 85% of the archipelago was covered in some form of forest [64]. Since then, there has been widespread forest loss (by fire and logging) and vertebrate extinctions [65]. This change is an archetypal example of the transgression of biophysical memory. Material and information legacies have been lost and replaced by others, including invasive species, propagule banks, novel predation regimes, and species adapted to the rescaled disturbance regime [66]. Alongside these changes, the ability of Māori (the indigenous people of Aotearoa-NZ) to access and use resources has been restricted or removed under various legislative frameworks developed by subsequent European colonisers, despite a formal treaty between Māori and the British crown - Te Tiriti o te Waitangi, 1840) guaranteeing these rights.

So, how can we return desired ecological and social-ecological memory to such disrupted ecosystems? The emphasis has been on biophysical responses such as excluding humans from parts of the landscape (e.g. island sanctuaries), controlling or eradicating invasive species (mammals and plants), limiting fire, and restoration planting. However, simply removing stressors and their legacies may not be sufficient to return ecological memory to these ecosystems given the very strong hysteresis some carry [67]. Efforts to restore these landscapes and their mauri (life-force) must be grounded in Mātaraunga Māori – that is, traditional Māori concepts of knowledge and its construction, and reinstate socio-ecological memory via, for example, practices of kaitiakitanga (guardianship, stewardship). Some interesting steps have been made in this direction. For example, the former Te Urewera National Park (which was the first National Park globally to be disestablished and then co-managed by the Crown and Tūhoe-the local indigenous people) and the Whanganui River have both been granted juristic personhood to provide new cultural frameworks to protect the health and wellbeing of this land and river, recognising and restoring their long-standing significance to Māori communities [36,68]. However, some of the social-ecological memories that underpin Mātaraunga Māori have been eroded as connections between

people and the landscape have been lost or stolen [33]. Adopting Mātaraunga Māori may be 'disruptive' (in a positive way) to 'normal' scientific approaches to knowledge generation and transmission [69] but, ultimately, they are complementary [70]. Exemplifying this complementarity, [54] demonstrate how palaeoecological data can be used to develop a range of place-based restoration baselines, while social-ecological memory can be used to develop selected restoration targets that are meaningful to local communities.

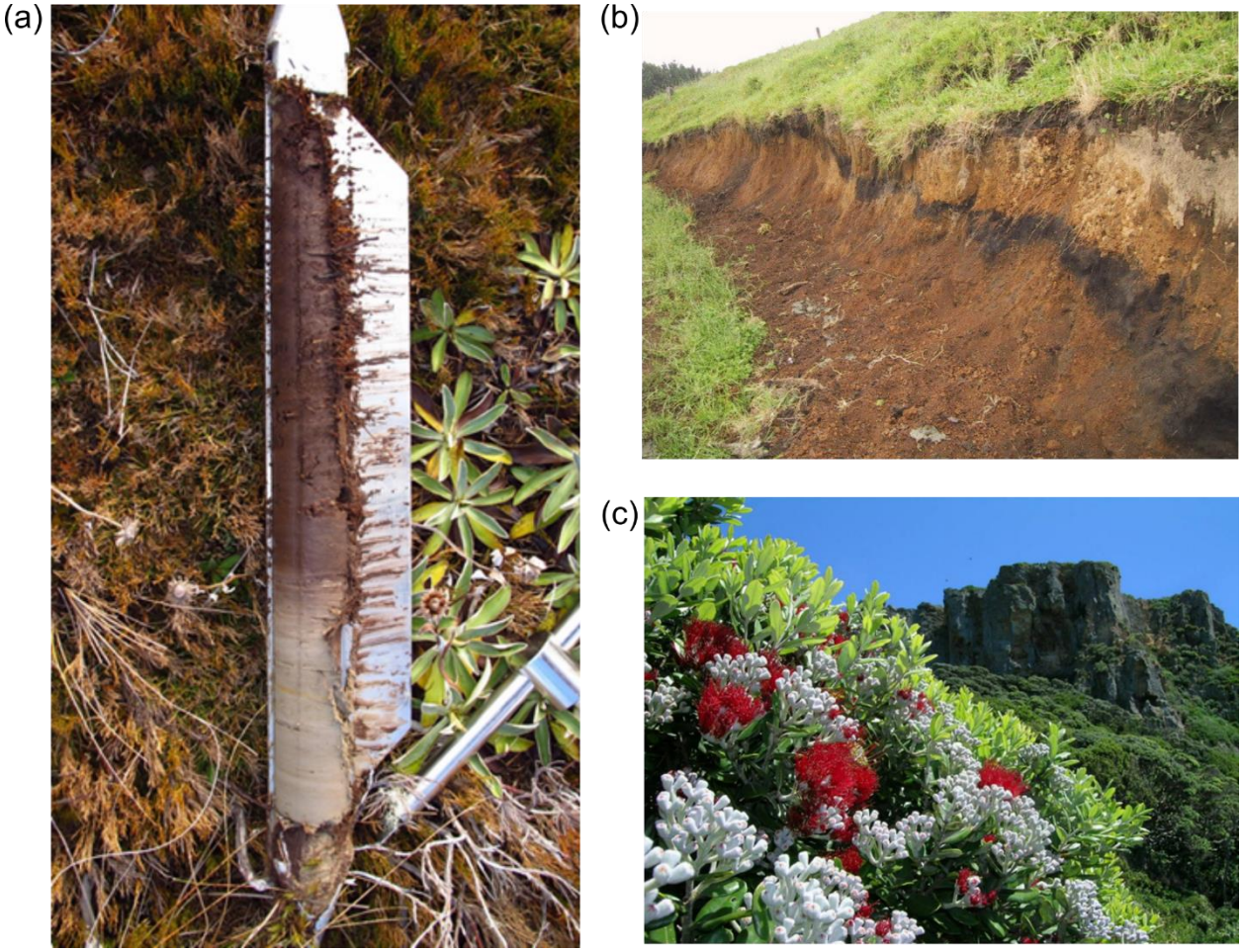

Figure B2 – Examples of memory from northern New Zealand forest landscapes: (a) and (b) the horizon of charcoal denoting the arrival of humans in Aotearoa-NZ c 1280 CE in sediment cores and soil horizons, and (c) pōhutakawa (*Meterosideros excelsa*) on Ririwha (Stephenson's island), where local iwi looking for baseline vegetation to restore some parts

588 of the island back to native forest, while keeping other parts of the island free so they can
589 rear sheep for their whanau. They also had aspirations to harvest seabirds from the island,
590 again needing to recall mātauranga and socio-ecological memory [54].

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Ecological and social-ecological memory are central to landscape restoration

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Highlights

- Ecological memory and social-ecological memory are deeply intertwined and are argued to be important components of restoration as they support resilience. Ecological memory comprises the entities persisting from the past (e.g. woody debris) and information legacies (adaptations or behaviours), and social-ecological memory comprises the institutions, knowledge, beliefs and practices developed by people that relate them to the environment.
- While memory is important for restoration it is not uniformly 'good'. Thus, it is not always the case that reinstating memory is desirable. Ill-sighted management interventions have left undesirable residuals and regimes, and social-ecological memory may be contested and maladaptive; forgetting may be as important as remembering.
- What is desirable in terms of restoration will always have a subjective element. Likewise, social-ecological memory is likely to be contested and reflect specific positions of power. There is an important place for counter-memory in developing restoration programs.
- There is a risk that efforts to integrate ecological and social-ecological memory into restoration fail to recognise its inherent dynamism, and so appeal to some pre-determined condition. Just as memory is dynamic, restoration that draws on it needs to be proactive and precautionary to be able to respond to emergent dynamics, contingencies and associated uncertainties.

Ecological and social-ecological memory are central to landscape restoration

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Outstanding questions

- The conceptualisation of ecological memory as comprising residuals and information legacy has been most frequently applied in the context of disturbance ecology. How applicable are these ideas to other forms of ecological and social-ecological change? And at what spatial and temporal scales?
- How best can we balance the need to reinstate ecological and social-ecology memory with the need to erase some memories of the past (legacies of inappropriate management interventions, cultural dispossession from the environment)? How do we identify these components?
- What is the place of social, as opposed to, social-ecological memory in environmental restoration?
- How can counter-memory and counter-narratives contribute to efforts to restore environmental systems?