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Supplementary information for

The influence of soil age on ecosystem structure and function across biomes

Author for correspondence:

Manuel Delgado-Baquerizo. E-mail: M.DelgadoBaquerizo@gmail.com

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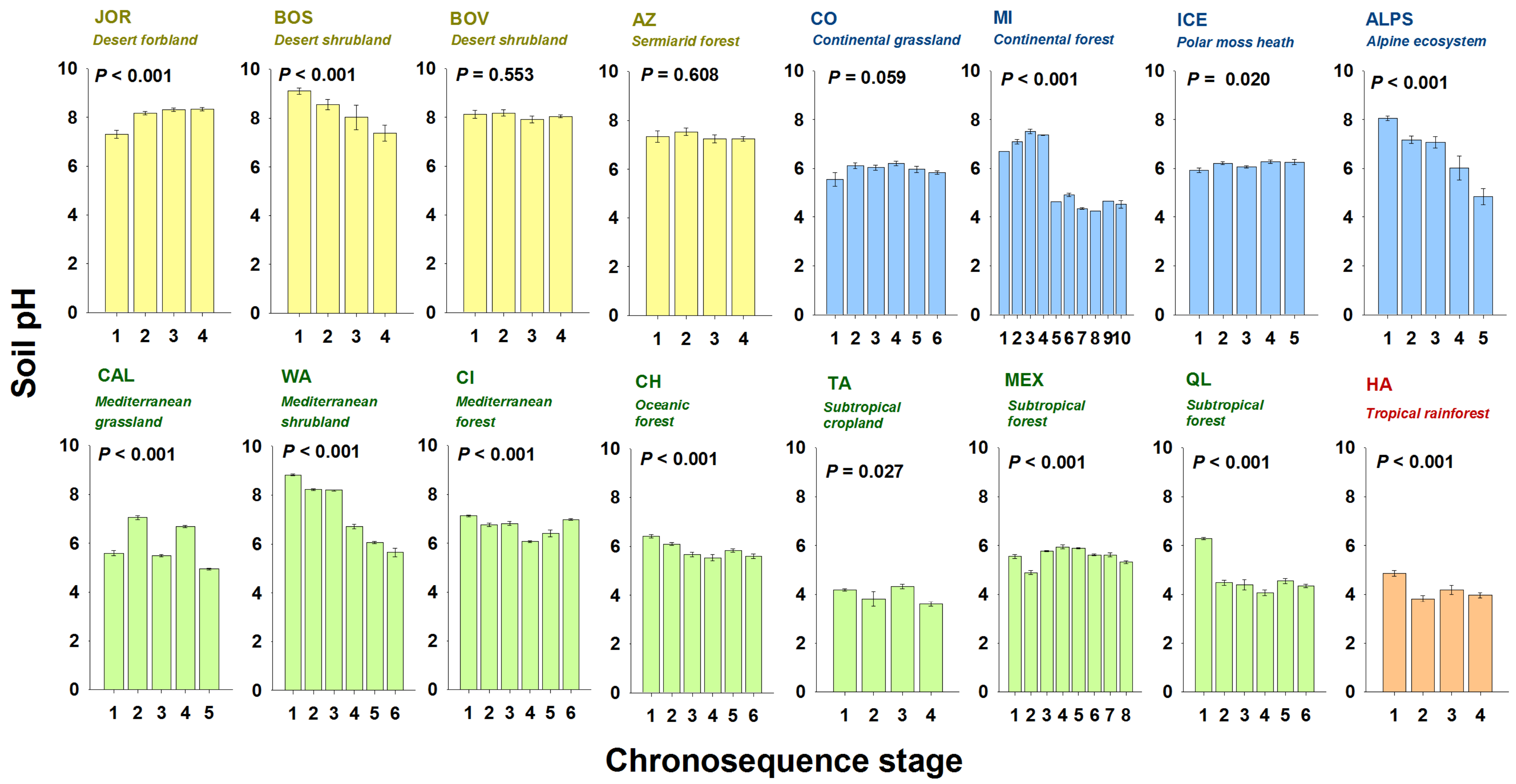
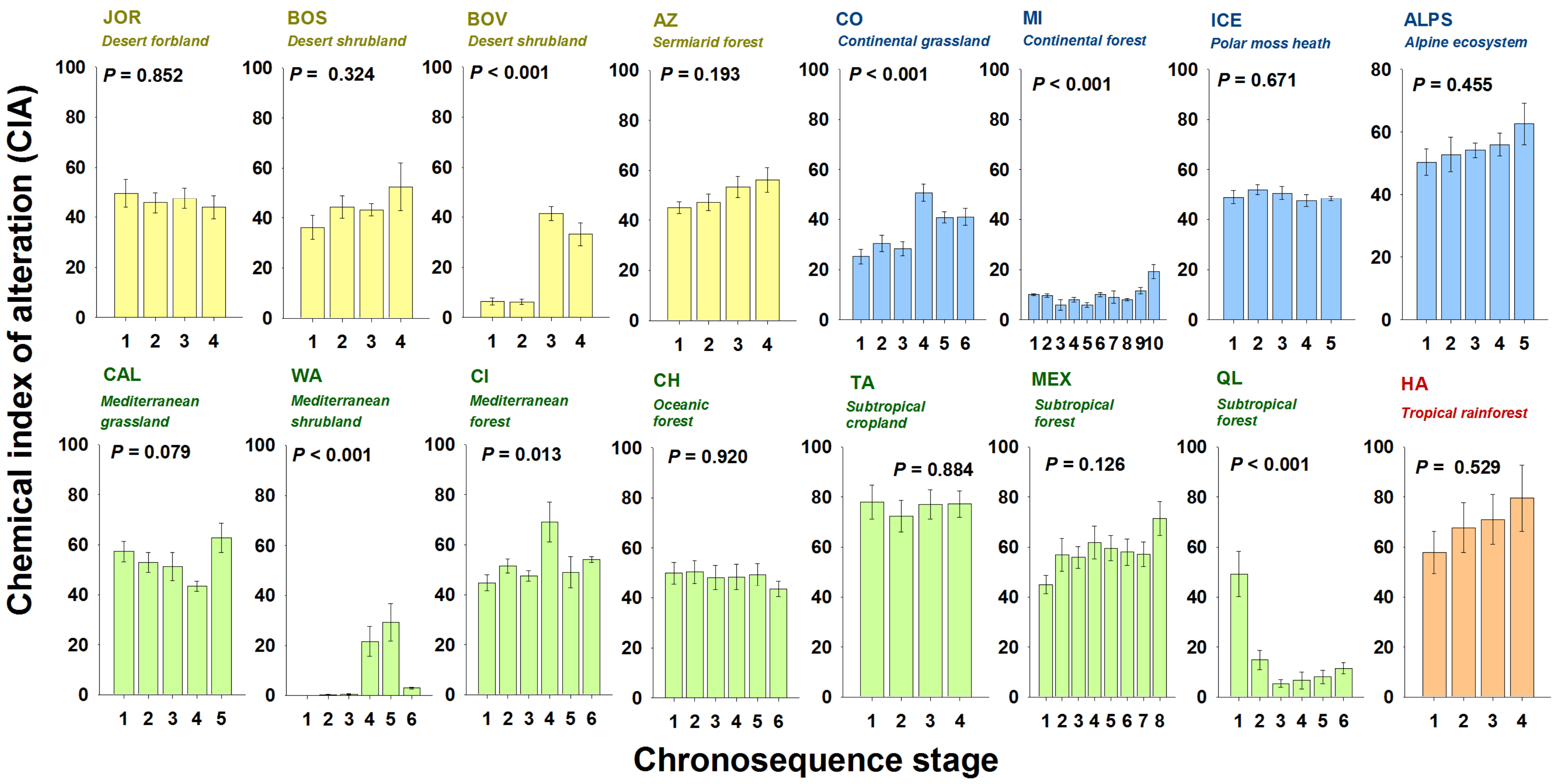
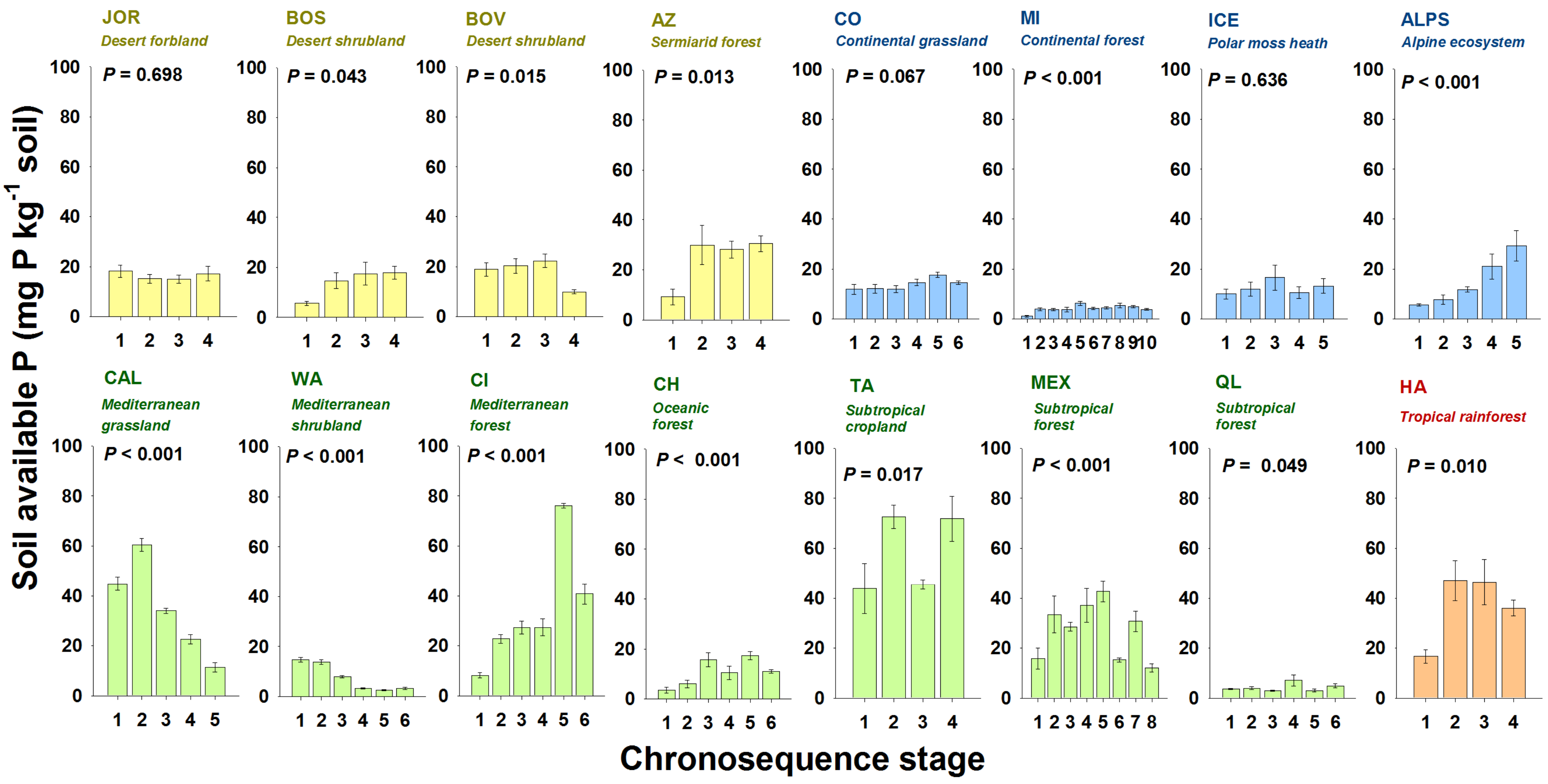


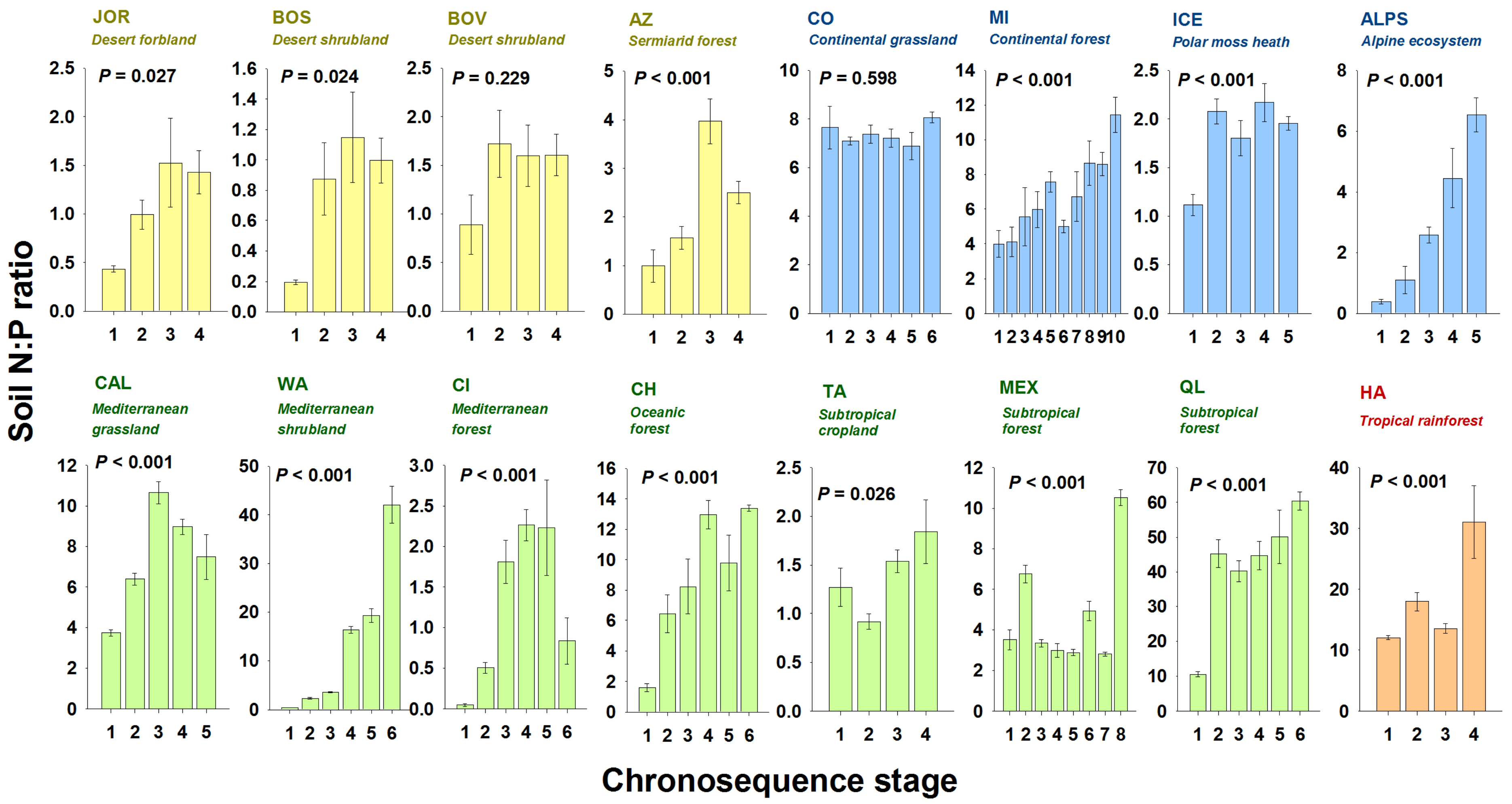
Supplementary Figure 1 | Changes soil pH during ecosystem development (mean ± SE). PERMANOVA P values are shown. Chronosequence stage was included as a fixed factor in these analyses (n = 5).



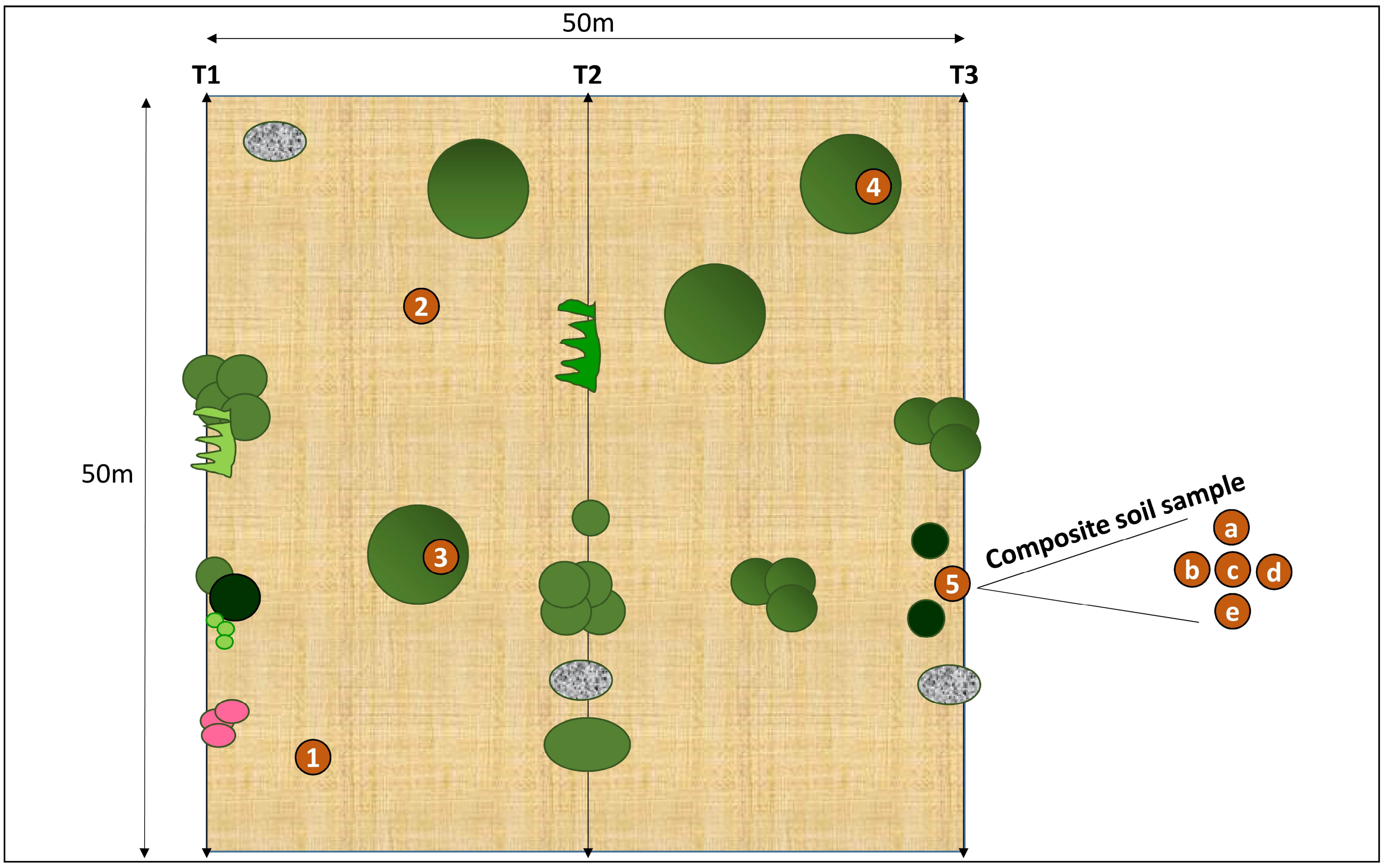
Supplementary Figure 2 | Changes in the chemical index of alternation during ecosystem development (mean ± SE). PERMANOVA P values are shown. Chronosequence stage was included as a fixed factor in these analyses (n = 5). CIA = %.



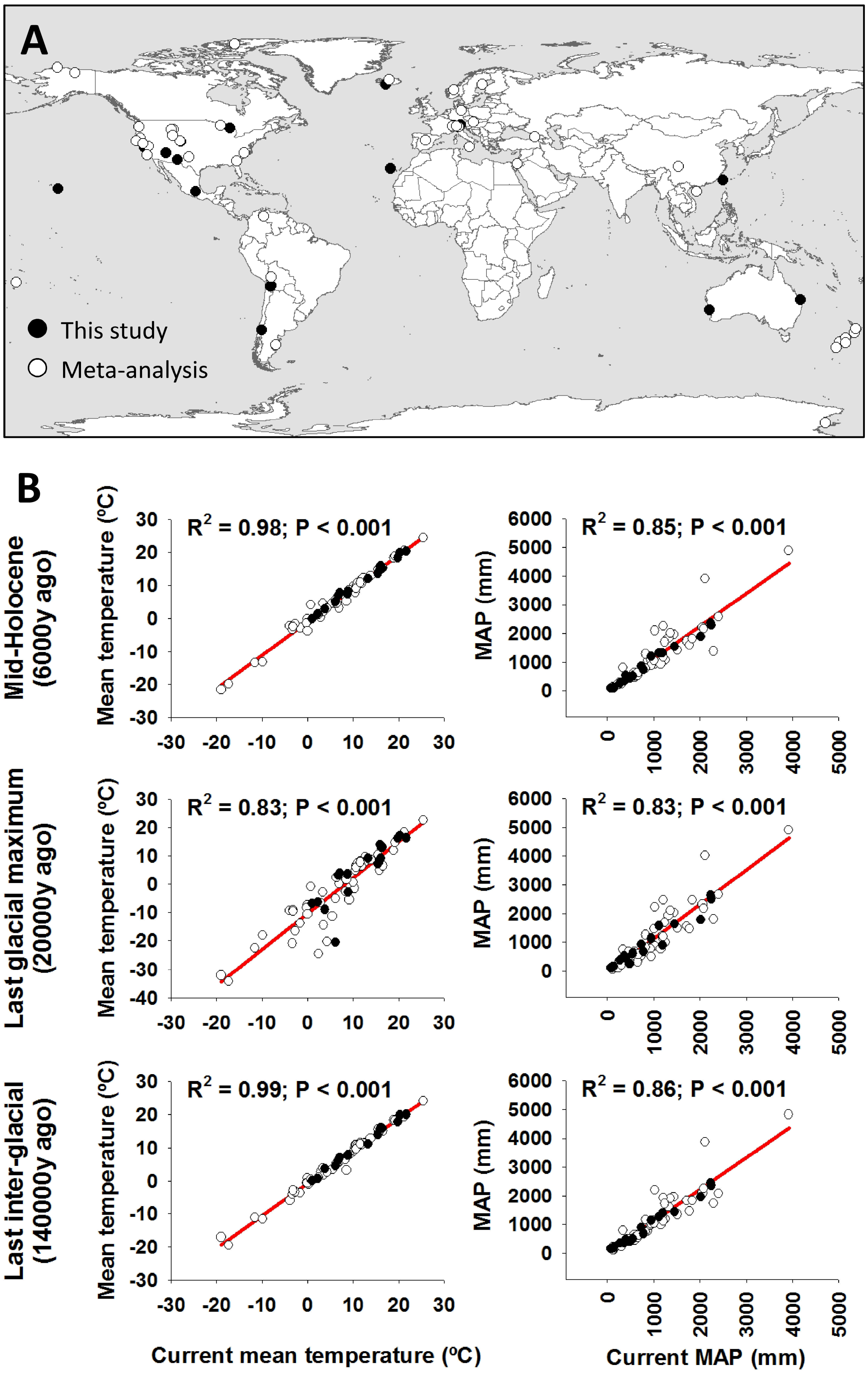
Supplementary Figure 3 | Changes in soil available P during ecosystem development (mean ± SE). PERMANOVA P values are shown. Chronosequence stage was included as a fixed factor in these analyses (n = 5).



Supplementary Figure 4 | Changes in the soil N:P ratio during ecosystem development (mean ± SE). PERMANOVA P values are shown. Chronosequence stage was included as a fixed factor in these analyses (n = 5).



Supplementary Figure 5 | Graphical representation of our sampling design implemented at each stage for each chronosequence. T = transect. Different circles represent different types of vegetation.



Supplementary Figure 6 | Relationship between current and past climates across 64 chronosequences. Panel A shows the location of the 64 soil chronosequences included in this study. Panel B includes the regression between current and past precipitation (MAP) and temperature for the 64 chronosequences (16 soil chronosequences in this study, and 48 soil chronosequences a meta-analysis) across three periods of time (6k, 20k and 140k years ago). Black circle = This study; White circle = Meta-analysis. P values were derived from ordinary least square regressions.

Supplementary Table 1 | Dominant vegetation community composition in each of the stages for the 16 soil chronosequences included in this study. See Fig. 1 for the location of these chronosequences. A previous reference including information on these chronosequences can be found at the bottom of this supplementary table.

Name	Stage	Dominant vegetation	Age (years)
ALPS[a]	1	*Saxifraga azoides, Saxifraga oppositifolia, Poa alpina, Linaria alpina, Artemisia gentipi*	10
	2	*Trifolium pallescens, Campanula scheuchzeri, Saxifraga oppositifolia, Saxifraga aizoides*	45
	3	*Kobresia myosuroides, Agrostis alpina, Alchemilla fissa, Trifolium pratense* spp., *Nivale*	125
	4	*Avenula versicolor, Carex sempervirens, Festuca halleri, Anthoxanthum alpinum*	10000
	5	*Fagus sylvatica, Abies alba, Acer pseudoplatanus, Picea abies, Quercus robur*	120000
AZ[b]	1	*Juniperus monosperma, Pinus edulis, Bouteloua gracilis*	900
	2	*Juniperus monosperma, Pinus edulis, Bouteloua gracilis*	55000
	3	*Juniperus monosperma, Pinus edulis, Bouteloua gracilis*	750000
	4	*Juniperus monosperma, Pinus edulis, Bouteloua gracilis*	3000000
BOS[c]	1	*Astragalus pusillus, Atriplex imbricata, Baccharis boliviensis, Baccharis tola, Ephedra breana, Haplopappus rigidus, Junellia seriphioides, Lycium chanar, Opuntia boliviensis*	25
	2	*Fabiana densa, Atriplex imbricata, Baccharis boliviensis, Lycium chanar, Baccharis tola, Haplopappus rigidus, Hoffmannseggia minor, Junellia seriphioides, Mutisia ledifolia, Nassella curviseta*	11400
	3	*Atriplex imbricata, Baccharis boliviensis, Haplopappus rigidus, Junellia seriphioides, Lycium chanar, Mutisia ledifolia, Nassella curviseta, Trichocereus atacamensis*	14100
	4	*Atriplex imbricata, Baccharis boliviensis, Cheilanthes ternifolia, Diplostephium cinereum, Ephedra breana, Fabiana densa, Lycium chanar, Mutisia ledifolia, Senecio dryophyllus, Senecio nutans, Stevia sp., Trichocereus atacamensis*	20000
BOV[c]	1	*Adesmia spinosa, Atriplex imbricata, Chuquiraga atacamensis. Frankenia triandra, Sisymbrium sp., Nassella curviseta*	25
	2	*Opuntia boliviensis, Acantholippia punensis, Atriplex imbricata, Chuquiraga atacamensis, Ephedra breana, Senecio dryophyllus, Sisymbrium sp.*	11400
	3	*Acantholippia punensis, Adesmia spinosa, Atriplex imbricata, Chuquiraga atacamensis, Nassella curviseta*	14100
	4	*Acantholippia punensis, Atriplex imbricata, Chuquiraga atacamensis, Senecio dryophyllus*	20000
CAL[d]	1	*Populus fremontii, Helianthus annuus, Amaranthus albus*	100
	2	*Quercus lobata, Silybum marianum, Hordeum murinum L*	3000
	3	*Festuca californica*	30000
	4	*Rytidosperma penicillatum*	600000
	5	*Festuca bromoides, F. myuros, Bromus hordaceous, Bromus diandrus*	3000000
CH[e]	1	*Gaultheria pumila, Racomitrium lanuginosum*	60
	2	*Lomatia hirsuta, Austrocedrus chilensis*	266
	3	*Araucaria araucana, Nothofagus antarctica*	776
	4	*Nothofagus dombeyi, Araucaria araucana*	3470
	5	*Nothofagus dombeyi, N. obliqua, N. alpina*	60000
	6	*Nothofagus dombeyi, N. alpina*	5000000
CI[f]	1	*Pinus canariensis*	525
	2	*Pinus canariensis, Erica arborea, Pterocephalus porphyranthus*	6000
	3	*Pinus canariensis, Adenocarpus viscosus, Chamaecytisus proliferus, Erica arborea*	40000
	4	*Pinus canariensis, Adenocarpus viscosus*	600000
	5	*Pinus canariensis, Cistus symphytifolius*	1100000
	6	*Pinus canariensis, Cistus symphytifolius*	1700000
CO[f]	1	*Juncus arcticus, Andropogon gerardii, Panicum virgatum*	5000
	2	*Andropogon gerardii, Panicum virgatum*	140000
	3	*Panicum virgatum, Poa compresa, Andropogon gerardii*	240000
	4	*Chrysopsis sp., Andropogon gerardii, L. cinquefoil*	640000
	5	*Andropogon gerardii, M. Burgia, Poa compresa,*	1000000
	6	*Andropogon gerardii, Poa compresa, M. Burgia*	2000000
HA[g]	1	*Metrosideros polymorpha, Morella faya, Vaccinium calycinum, Ilex anomala, Cheirodendron trigynum, Cibotium glaucom, Hedychium gardnerianum, Isoetes sp. (grass), Coprosma sp., Myrsine lessertiana, Dicranopteris linearis, Machaerina angustifolia, Anemone hupehensis,*	300
	2	*Metrosideros polymorpha, Cheirodendron trigynum, Cibotium glaucom, Cibotium menziesii, Ilex anomala, Freycinetia arborea, Astelia menziesii, Melicope clusiifolia, Vaccinium calycinum, Nephrolepis sp., Asplenium* spp. *(multi), Athyrium microphyllum, Ilex myrtifolia, Peperomia sp., Polypodium sp.,*	20000
	3	*Metrosideros polymorpha, Cibotium glaucom, Cibotium menziesii, Hedychium gardnerianum, Vaccinium calycinum, Cheirodendron trigynum, Psidium cattleianum, Dicranopteris linearis, Asplenium sp., Melicope clusiifolia, Myrsine sandwicensis, Elaphoglossum sp., Polygonum punctatum Tibouchina herbacea, Peperomia sp., Psilotum nudum*	150000
	4	*Metrosideros polymorpha, Hedychium gardnerianum, Dicranopteris linearis, Pittosporum gayanum, Psidium cattleianum, Astelia menziesiana, Morella faya, Vaccinium meyenianum, Smilax hawaiensis, Elaphoglossum spp, Elaeocarpus bifidus, Clerodendrum sp., Alyxia oliviformis,*	4100000
ICE[h]	1	*Racomitrium lanuginosum; Empetrum nigrum; Stereocaulon vesuvianum*	172
	2	*Racomitrium lanuginosum; Empetrum nigrum; Arctostaphylos uva-ursi*	463
	3	*Racomitrium lanuginosum; Betula nana; Hylocomium splendens; Empetrum nigrum; Arctostaphylos uva-ursi*	628
	4	*Racomitrium lanuginosum; Salix phylicifolia; Empetrum nigrum; Hylocomium splendens*	717
	5	*Racomitrium lanuginosum; Empetrum nigrum; Betula nana; Hylocomium splendens*	859
JOR[i]	1	*Opuntia phaeacantha. var., Boerhavia* spp., *Eragrostis lehmanniana.*	1100
	2	*Sporobolus contractus, Muhlenbergia porteri, Larrea tridentata, Ephedra trifurca.*	2200
	3	*Boerhavia* spp., *Larrea tridentata .*	8000
	4	*Boerhavia* spp., *Ephedra trifurca Torr., Erioneuron pulchellum*	25000
MEX[j]	1	*Pinus montezumae, Bacharis conferta, Alnus firmifolia, Penstemon sp.*	1000
	2	*Abies religiosa, Arbutus xalapensis, Pinus herrerae, Bacharis conferta, Pinus montezumae, Penstemon sp., Bacharis conferta*	1835
	3	*Pinus montezumae, Pinus pseudostrobus, Alnus firmifolia, Quercus laurina,*	3800
	4	*Pinus montezumae, Alnus firmifolia*	6200
	5	*Pinus montezumae, Bacharis conferta, Buddleja parviflora*	8000
	6	*Pinus patula, Alnus firmifolia, Pinus montezumae, Senecio sp.*	10000
	7	*Pinus ayacahuite, Pinus pseudostrobus, Pinus montezumae*	30500
	8	*Pinus montezumae, Abies religiosa, Quercus laurina, Penstemos sp., Bacharis conferta*	100000
MI[k]	1	*Amophilous breviligulata, Agropyron dasystachium, Cerisium pitheri, Arctostaphylos uva-ursi*	73
	2	*Amophilous breviligulata, Agropyron dasystachium, Cerisium pitheri, Arctostaphylos uva-ursi, Schizachyrium scoparium*	113
	3	*Arctostaphylos uva-ursi, Juniperus communis, Pinus strobus*	163

	4	*Pteridium aquilinum, Pinus resinosa, Abies sp.*	243
	5	*Gaultheria procumbens, Pinus resinosa,*	485
	6	*Abies balsamea, Pinus resinosa, Juniperus communis*	863
	7	*Abies balsamea, Pinus resinosa, Pinus strobus*	1400
	8	*Pinus resinosa, Vaccinium myrtilloides, Gaultheria procumbens*	2500
	9	*Pinus resinosa, Vaccinium myrtilloides, Gaultheria procumbens*	3200
	10	*Pinus resinosa, Pinus strobus, Gaultheria procumbens*	4000
QL[l]	1	*Eucalyptus tessellaris, Angophora costata, Eucalyptus intermedia, Casuarina littoralis, Melaleuca quinquenerva, Banksia integrifolia, Banksia serrata, Macrozamia* spp., *Acacia aulacocarpa, Acacia flavescens, Cassytha paniculata, Gahnia sieberiana,*	3600
	2	*Eucalyptus tessellaris, Angophora costata, Eucalyptus intermedia, Casuarina littoralis, Melaleuca quinquenerva, Banksia integrifolia, Banksia serrata, Macrozamia* spp., *Acacia aulacocarpa, Acacia flavescens, Cassytha paniculata, Gahnia sieberiana,*	6700
	3	*Eucalyptus tessellaris, Angophora costata, Eucalyptus intermedia, Casuarina littoralis, Melaleuca quinquenerva, Banksia integrifolia, Banksia serrata, Macrozamia* spp., *Acacia aulacocarpa, Acacia flavescens, , Cassytha paniculata, Gahnia sieberiana,*	134000
	4	*Eucalyptus tessellaris, Angophora costata, Eucalyptus intermedia, Casuarina littoralis, Melaleuca quinquenerva, Banksia integrifolia, Banksia serrata, Macrozamia* spp., *Acacia aulacocarpa, Acacia flavescens, Cassytha paniculata, Gahnia sieberiana,*	176000
	5	*Eucalyptus tessellaris, Angophora costata, Eucalyptus intermedia, Casuarina littoralis, Melaleuca quinquenerva, Banksia integrifolia, Banksia serrata, Macrozamia* spp., *Acacia aulacocarpa, Acacia flavescens, Cassytha paniculata, Gahnia sieberiana,*	324000
	6	*Eucalyptus tessellaris, Angophora costata, Eucalyptus intermedia, Casuarina littoralis, Melaleuca quinquenerva, Banksia integrifolia, Banksia serrata, Macrozamia* spp., *Acacia aulacocarpa, Acacia flavescens, Cassytha paniculata, Gahnia sieberiana,*	716000
TA[m]	1	*Tea camellia*	28000
	2	*Tea camellia*	105000
	3	*Tea camellia*	322000
	4	*Tea camellia*	399000
WA[n]	1	*Acacia cyclops, Acacia rostellifera, Scaevola crassifolia, Olearia axillaris, Spyridium globulosum*	100
	2	*Melaleuca systena, Acacia lasiocarpa, Acacia rostellifera*	1000
	3	*Melaleuca systena, Acacia lasiocarpa, Acacia rostellifera*	6500
	4	*Melaleuca systena, Banksia leptophylla, Calothamnus quadrifidus*	120000
	5	*Banksia menziesii, Banksia attenuata, Mesomelaena pseudostygia, Hibbertia hypericoides*	480000
	6	*Banksia menziesii, Jacksonia floribunda, Banksia leptophylla*	2000000

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[b]Selmants, P.C., Hart S.C. (2008). Substrate age and tree islands influence carbon and nitrogen dynamics across a retrogressive semiarid chronosequence. Global Biogeochemical Cycles 22, GB1021.

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[d]Doetterl S. et al. (2019). Links among warming, carbon and microbial dynamics mediated by soil mineral weathering. Nature Geoscience 11, 589-593.

[e]Pérez, C.A. et al. (2017). Biological nitrogen fixation in a post-volcanic chronosequence from south-central Chile. Biogeochemistry 132, 23-36.

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[i]Lajtha K., Schlesinger W.H. (1988). The Biogeochemistry of Phosphorus Cycling and Phosphorus Availability Along a Desert Soil Chronosequence. Ecology 69, 24-39.

[j]Peña-Ramírez, V.M. et al. (2015). Rates of pedogenic processes in a chronosequence of volcanic ash soils of Central Mexico. Quaternary International 376, 19-33.

[k]Williams, M.A. et al. (2013). Bacterial communities in soil mimic patterns of vegetative succession and ecosystem climax but are resilient to change between seasons. Soil Biology and Biochemistry 57, 749-757.

[l]Walker, J. et al. (2018). Dating the Cooloola coastal dunes of South-Eastern Queensland, Australia. Marine Geology 398, 73–85.

[m]Tsai, H. et al. (2006). A river terrace soil chronosequence of the pakua tableland in central Taiwan. Soil Science 171, 167-179.

[n]Laliberté, E. et al. (2014). Environmental filtering explains variation in plant diversity along resource gradients. Science 345, 1602-1605.

Supplementary Table 2 | Main characteristics for the 48 soil age chronosequences included in the result cross-validations for study. See Appendix S1 for a list of paper including this meta-data. See Fig. 3A for the location of these chronosequences.

Chronosequence	Climate	Age range (years)	Substrate origin	Region	Vegetation type
Altamaha and Ohoopee River Valley, USA	Temperate	0-77000	Dune	Middle Latitudes	Grassland
Arklio Glacier, Canada	Cold	300-17000	Glacier	Polar circle	Unvegetated
Barrow Peninsula Canada	Cold	25-3750	Sedimentary	Polar circle	Grassland
Cowlitz River, WA, USA	Temperate	250-1200000	Sedimentary	Middle Latitudes	Forest
Damma Glacier, Switzerland	Cold	7-3000	Glacier	Middle Latitudes	Shrubland
Danube floodplain, Austria	Temperate	2-7500	Sedimentary	Middle Latitudes	Grassland
Elbe River, Germany	Temperate	100-6000	Sedimentary	Middle Latitudes	Forest
Franz Josef Glacier, New Zealand	Temperate	1-120000	Glacier	Middle Latitudes	Forest
Gletsch, Switzerland	Cold	150-10500	Glacier	Middle Latitudes	Grassland
Colorado Front Range, USA	Cold	225-11000	Glacier	Middle Latitudes	Forest
Golfo San Jorge, Argentina	Arid	1376-6238	Volcanic	Middle Latitudes	Shrubland
Haast dune system, New Zealand	Temperate	181-6500	Dune	Middle Latitudes	Shrubland
Hailuogou chronosequence, China	Temperate	0-1400	Glacier	Middle Latitudes	Forest
Hainan Island, China	Tropical	90-2300000	Volcanic	Tropics	Forest
Henares River, Spain	Temperate	120000-750000	Sedimentary	Middle Latitudes	Grassland
Kane Alluvial Fans, USA	Arid	5000-585000	Sedimentary	Middle Latitudes	Grassland
Lubbock Lake, USA	Arid	175-4750	Sedimentary	Middle Latitudes	Grassland
Makhtesh Ramon crater, Israel	Arid	60000-443000	Volcanic	Middle Latitudes	Forest
Manawatu, New Zealand	Temperate	0-10000	Dune	Middle Latitudes	Grassland
Supsa River basin, USA	Cold	1000-300000	Sedimentary	Middle Latitudes	Forest
Mono Lake	Temperate	47-2400	Dune	Middle Latitudes	Shrubland
Montana, USA	Cold	7_2000	Sedimentary	Middle Latitudes	Grassland
Morteratsch, Switzerland	Cold	1-12500	Glacier	Middle Latitudes	Grassland
Mt Shasta, USA	Temperate	27-1200	Volcanic	Middle Latitudes	Forest
Mururata Mountain, Bolivia	Temperate	900-20000	Glacier	Tropics	Grassland
Oberaar, Switzerland	Cold	150-11450	Glacier	Middle Latitudes	Grassland
Reefton, New Zealand	Temperate	1000-130000	Volcanic	Middle Latitudes	Forest
Rhone, Switzerland	Cold	150-11600	Glacier	Middle Latitudes	Grassland

San Francisco California, USA	Temperate	100000-500000	Sedimentary	Middle Latitudes	Forest
Schmadri, Switzerland	Cold	3500-11500	Glacier	Middle Latitudes	Grassland
Sicily, Italy	Temperate	60-31700	Volcanic	Middle Latitudes	Forest
Sierra Nevada Nat. Park, Venezuela	Temperate	1-11540	Volcanic	Tropics	Forest
South Eureka, USA	Temperate	3900-240000	Sedimentary	Middle Latitudes	Grassland
Storbreen glacier, Norway	Cold	70-9000	Glacier	Middle Latitudes	Grassland
The Lambardalur Cirque, Iceland	Cold	250-9000	Glacier	Middle Latitudes	Grassland
The McMurdo Valleys, Antarctica	Cold	14-4155	Glacier	Polar circle	Unvegetated
Tonga Islands, Tonga	Tropical	100-100000	Volcanic	Tropics	Forest
Toolik Lake, USA	Cold	5-4800000	Glacier	Polar circle	Forest
Val di Rabbi, Switzerland	Cold	4730-17300	Glacier	Middle Latitudes	Forest
Val Mulix, Switzerland	Cold	6900-19200	Glacier	Middle Latitudes	Grassland
Västerbotten, Sweden	Cold	90-6800	Glacier	Middle Latitudes	Forest
Ventura, USA	Temperate	700-80000	Sedimentary	Middle Latitudes	Grassland
Volcanic field, NZ	Temperate	1750-14000	Volcanic	Middle Latitudes	Forest
Waitutu, New Zealand	Temperate	3000-291000	Sedimentary	Middle Latitudes	Shrubland
Whataroa and Poerua Rivers, NZ	Temperate	14000-60000	Glacier	Middle Latitudes	Forest
Wind River Range, USA	Arid	150-1200000	Sedimentary	Middle Latitudes	Grassland
Wisconsin Glacier, USA	Cold	9500-13500	Glacier	Middle Latitudes	Forest
Yuba Rivers, Sacramento, USA	Temperate	0-1600000	Sedimentary	Middle Latitudes	Grassland

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Supplementary Table 3 | List of ecosystem properties. Replicate-level = 435 samples (5 replicates/plot). Transect level = 261 transects (3 transects/plot). Plot-level = 87 plots.

#	Group	Ecosystem properties	Details	n	Rationale
1	**Soil properties**	**Chemical index of alteration (CIA index)**	$Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)$ (molecular proportions in %, based on total elements and not corrected for carbonates and apatite)	Replicate-level	Soil properties drive ecosystem change and are key regulators of ecosystem functioning. Texture refers to the size of the particles that make up the soil (clay, silt and sand). Soil pH is a measure of the acidity and alkalinity in soils. Total soil P provides information on the bedrock-associated P stocks. The total base cation reserve and the chemical index of alteration (aluminum saturation) informs on the degree of soil weathering, because Ca, Mg, K and Na are largely washed out during soil chemical alteration relative to other elements such as Al.
2		**Total base cation reserves (TBR index)**	Ca+ Na + K + Mg ($cmol_c$ kg^{-1})	Replicate-level	
3		**Fine texture**	Clay+silt (%)	Plot-level	
4		**Soil pH**	Soil pH	Replicate-level	
5		**Soil total P-H_2SO_4**	Total soil P-H_2SO_4 extraction (mg P kg^{-1} soil)	Replicate-level	
6		**Soil total P-HF**	Total soil P- hydrofluoric acid (-PH) extraction (mg P kg^{-1} soil)	Replicate-level	
7	**Soil stoichiometry**	**Soil C:P ratio**	Soil C:P ratio	Replicate-level	Ecosystem stoichiometry, and notably soil C:N:P stoichiometry, informs on the relative balance of carbon, nitrogen and phosphorus in the soil system. Ecosystem stoichiometry is a major regulator of important ecosystem functions such as organic matter mineralization and nutrient uptake.
8		**Soil N:P ratio**	Soil N:P ratio	Replicate-level	
9		**Soil C:N ratio**	Soil C:N ratio	Replicate-level	
10	**Water resources**	**Potential infiltration**	Potential water infiltration (ml water s^{-1})	Replicate-level	Hydrological functions regulate the availability and quality of fresh water via water purification (e.g., infiltration) and retention (water holding capacity). Water holding capacity provides information on the potential capacity of a given soil to retain water and potential water infiltration provide a measurement of the infiltration capacity for a given soil. Hydrological processes regulate the availability of hydric resources for plants, animals and microbes.
11		**Water holding capacity**	Soil water holding capacity (%)	Replicate-level	
12	**Nutrient cycling**	**Available P**	Soil available phosphorus (mg P kg^{-1} soil)	Replicate-level	Nutrient recycling, represented by soil inorganic N and P pools, is one of the most important processes controlling the productivity of plants and microbes in terrestrial ecosystems. Nutrient recycling is a supporting service that controls the movement and exchange of matter back into the production of biomass.
13		**Available N**	Soil available nitrogen (mg N kg^{-1} soil)	Replicate-level	
14	**C cycling**	**Soil C stocks**	Soil carbon stocks (kg C m^{-2})	Replicate-level	Soils contain more than twice the amount of C stored in vegetation globally. Soil C storage and respiration rates are essential ecosystem functions that regulate the amount of CO_2 in the atmosphere, and therefore the Earth's climate. C-source degradation and extracellular enzyme activities are provided by soil bacteria, fungi, and archaea and are involved in the decomposition and mineralization of soil organic matter from complex polymers to simpler monomers. Enzyme activities and C degradation functions contribute to regulating the amount of litter and organic matter in our ecosystems.
15		**Soil respiration**	Soil respiration (µg CO_2-C g^{-1} soil day^{-1})	Plot-level	
16		**Sugar degradation**	Activity of beta-glucosidase (nmol activity g^{-1} dry soil hr^{-1})	Replicate-level	
17		**Chitin degradation**	Activity of N-acetylglucosaminidase (nmol activity g^{-1} dry soil hr^{-1})	Replicate-level	
18		**P mineralization**	Activity of phosphatase (nmol activity g^{-1} dry soil hr^{-1})	Replicate-level	
19		**Lignin degradation**	Lignin induced respiration (µg CO_2-C g^{-1} h^{-1})	Replicate-level	
20		**Glucose respiration**	Glucose respiration (µg CO_2-C g^{-1} soil day^{-1})	Replicate-level	

21	**Plant production**	**Plant productivity**	NDVI index (250m resolution)	Plot-level	Plant production is a key ecosystem process that supports important provisioning services such as food and fiber production, and that maintains ecosystem functioning via litter inputs. The proportion of woody plants present provides important information on the availability of timber resources, which are critical materials for building and construction needs.
22		**Wood resources**	Relative abundance of woody plants (%)	Plot-level	
23	**Vegetation composition**	**Proportion of forbs**	Proportion of forbs (%)	Transect-level	The community composition (%) of major functional groups of plants including forbs, grasses, shrubs and trees, provides essential structural information on the within-plot organization of vegetation. Vegetation structure is a major regulator of ecosystem functioning and often changes greatly during ecosystem development.
24		**Proportion of grasses**	Proportion of grasses (%)	Transect-level	
25		**Proportion of shrubs**	Proportion of shrubs (%)	Transect-level	
26		**Proportion of trees**	Proportion of trees (%)	Transect-level	
27	**Microbial structure**	**Total microbial biomass**	Microbial PLFAs content (nmol PLFA g^{-1} dry soil)	Replicate-level	Fungal and bacterial biomass and ratios provide structural information on the dominant type of microbes in soil food webs. Microbial biomass is a major controller of ecosystem functioning. The relative abundance of mycorrhizal fungi provides information on the potential capacity of soil to establish symbiosis with plants.
28		**Bacterial biomass**	Bacterial PLFAs content (nmol PLFA g^{-1} dry soil)	Replicate-level	
29		**Fungal biomass**	Fungal PLFAs content (nmol PLFA g^{-1} dry soil)	Replicate-level	
30		**Fungal: bacterial ratio**	Fungal: bacterial PLFAs ratio	Replicate-level	
31		**Ectomycorrhizal fungi**	Soil ectomycorrhizal fungi (%)	Replicate-level	
32		**Arbuscular mycorrhizal fungi**	Arbuscular mycorrhizal fungi (%)	Replicate-level	

Supplementary Table 4 | State factors of ecosystem development included in this study.

#	Group of variables	Variable	Units	Rationale
1	**Soil age**	Quantitative soil age	Estimated soil age in years (log-transformed)	Soil age is expected to be a fundamental predictor of the changes in ecosystem structure and function over time.
2		Semi-quantitative age	Standardized soil age (0-1) based on chronosequence stage calculated for each chronosequence independently	
3		Categorical soil age	Thousands of years = 1, hundreds of thousands of years = 2, millions of years = 3	
4	**Climate**	Maximum temperature	ºC	Climate is one of the major controllers of the changes in ecosystem function and structure over time. Temperature and precipitation control the rates of biological and chemical activity and thus regulates the rate of ecosystem development. Soils can develop faster in wetter and warmer climates.
5		Minimum temperature	ºC	
6		Temperature seasonality	standard deviation *100	
7		Mean diurnal temperature range	ºC	
8		Mean annual precipitation	mm	
9		Precipitation seasonality	Coefficient of Variation, %	
10		Climatic biome type	Biome (0 = mesic, 1 = dryland). Drylands have an Aridity Index < 0.65 and Mesic have an Aridity Index > 0.65, where the Aridity Index = Precipitation / Potential Evapotranspiration	
11	**Vegetation type**	Coniferous forests	0/1	Vegetation type represents one of the five major state factors that regulate soil and ecosystem development (i.e., organisms). Different types of vegetation types (forest, grasslands or shrublands) have different capacities to regulate soil erosion, accumulate plant litter and humus and influence microbial activity.
12		Angiosperm forests	0/1	
13		Grassland	0/1	
14		Shrubland	0/1	
15	**Parent material**	Chronosequence substrate: Sand dune	0/1	Parent material is a fundamental driver of ecosystem structure and function because it is the key point of origin of many mineral nutrients and because it affects soil properties such as texture and pH, and influences soil formation rates.
16		Chronosequence substrate: Volcanic	0/1	
17		Chronosequence substrate: Sedimentary	0/1	
18		Lithology: Basic volcanic rocks	0/1	
19		Lithology: Siliciclastic sedimentary rocks	0/1	
20		Lithology: Metamorphic rocks	0/1	
21		Lithology: Carbonate sedimentary rocks	0/1	
22		Lithology: Evaporites	0/1	
23		USDA soil class: Orthods	0/1	
24		USDA soil class: Orthents	0/1	
25		USDA soil class: Ustolls	0/1	
26		USDA soil class: Xerolls	0/1	
27		USDA soil class: Ustox	0/1	
28	**Topography**	Elevation	mm	Topography influences exposure to climate, fire, and other natural and anthropogenic factors, and regulates important ecosystem properties such as nutrient cycling, C stocks, plant productivity and soil properties.
29		Slope	Degrees from horizontal	
30		Aspect class	Four topographic orientation classes based on their levels of exposure to solar radiation*. **Class 1:** Lowest levels of radiation (343-359º and 0-62º in the Northern Hemisphere, and 153-252º in the Southern Hemisphere) **Class 2:** Low-medium levels of radiation (63-116º and 298-342º in the Northern Hemisphere, and 117-152º and 253-297º in the Southern Hemisphere) **Class 3:** Medium-high levels of radiation (117-152º and 253-297º in the Northern Hemisphere, and 63-116º and 298-342º in the Southern Hemisphere)	

	Class 4: Highest levels of radiation (153-252º in the Northern Hemisphere, and 343-359º and 0-62º in the Southern Hemisphere)

*Parker, A.J. (1982) The topographic relative moisture index: An approach to soil-moisture assessment in mountain terrain. *Physical Geography* 3, 160-168.

Supplementary Table 5 | P-values arising from Variation Partitioning modeling in Fig. 1. See Supplementary Table 4 for a list of predictors and a rationale on their importance. See Supplementary Table 3 for a list of ecosystem structural and functional properties and a rationale for their significance.

Ecosystem property	n	Soil age	Climate	Vegetation	Parent material	Topography
Chemical Index of Alteration	435	<0.001	<0.001	<0.001	<0.001	<0.001
Total base cation reserve	435	<0.001	<0.001	<0.001	<0.001	<0.001
Fine texture	87	0.015	<0.001	0.025	<0.001	0.102
Soil pH	435	<0.001	<0.001	<0.001	<0.001	<0.001
Soil total P -H2SO4	435	<0.001	<0.001	<0.001	<0.001	<0.001
Soil total P -HF	435	0.043	<0.001	<0.001	<0.001	<0.001
Soil C:P ratio	435	<0.001	<0.001	<0.001	<0.001	<0.001
Soil N:P ratio	435	<0.001	<0.001	<0.001	<0.001	<0.001
Soil C:N ratio	435	0.002	<0.001	<0.001	<0.001	<0.001
Potential infiltration	435	<0.001	<0.001	<0.001	<0.001	<0.001
Water holding capacity	435	0.031	<0.001	<0.001	<0.001	<0.001
Available P	435	<0.001	<0.001	<0.001	<0.001	<0.001
Available N	435	0.002	<0.001	<0.001	<0.001	0.108
Soil C stocks	435	<0.001	<0.001	<0.001	<0.001	<0.001
Soil respiration	87	0.198	0.008	0.004	0.020	0.195
Sugar degradation	435	<0.001	<0.001	<0.001	<0.001	<0.001
Chitin degradation	435	<0.001	<0.001	0.033	<0.001	<0.001
P mineralization	435	<0.001	<0.001	<0.001	<0.001	<0.001
Lignin degradation	435	0.145	0.002	0.061	0.011	0.004
Glucose respiration	87	0.923	<0.001	<0.001	<0.001	0.047
Plant productivity	435	0.007	<0.001	<0.001	<0.001	<0.001
Wood resources	87	0.342	<0.001	<0.001	<0.001	0.303
Proportion of forbs	261	0.074	<0.001	<0.001	<0.001	0.605
Proportion of grasses	261	<0.001	<0.001	<0.001	<0.001	0.01
Proportion of shrubs	261	0.689	<0.001	<0.001	<0.001	<0.001
Proportion of trees	261	0.186	<0.001	<0.001	<0.001	<0.001
Total microbial biomass	435	<0.001	<0.001	<0.001	<0.001	0.008
Biomass bacteria	435	<0.001	<0.001	<0.001	<0.001	<0.001
Biomass fungi	435	<0.001	<0.001	<0.001	<0.001	0.015
Fungi: bacteria ratio	435	0.006	<0.001	<0.001	<0.001	0.006
Arbuscular mycorrhizal fungi	435	0.551	<0.001	<0.001	<0.001	<0.001
Ectomycorrhizal fungi	435	0.809	<0.001	<0.001	<0.001	0.139

Supplementary Table 6 | Selected relationships between quantitative soil age and ecosystem properties across major biome categories (drylands vs. mesic) and substrate types. P values were derived from ordinary least square regressions.

Selected relationships	Ecosystem factor	n	R^2	Slope	P-value
Quantitative soil age - Soil pH	Drylands	200	0.298	-0.436	<0.001
	Mesic	235	0.478	-0.587	<0.001
Quantitative soil age - TRB	Drylands	200	0.158	-126.699	<0.001
	Mesic	235	0.055	-46.475	<0.001
Quantitative soil age - NPP	Drylands	40	0.161	0.051	0.010
	Mesic	47	0.444	0.114	<0.001
Quantitative soil age - Proportion of trees	Drylands	120	0.142	4.881	0.000
	Mesic	141	0.037	4.521	0.022
Quantitative soil age - CIA	Sand dune substrate	110	0.020	1.318	0.140
	Other substrates	325	0.046	2.579	<0.001
Quantitative soil age - Soil total P-HF	Sand dune substrate	110	0.156	-21.226	<0.001
	Other substrates	325	0.009	-54.585	0.081
Quantitative soil age - Available P	Sand dune substrate	110	0.057	-0.632	0.012
	Other substrates	325	0.121	4.383	<0.001
Quantitative soil age - Soil N:P	Sand dune substrate	110	0.606	10.982	<0.001
	Other substrates	325	0.122	1.333	<0.001
Quantitative soil age - Soil C stocks	Sand dune substrate	110	0.335	0.263	<0.001
	Other substrates	325	0.107	0.690	<0.001
Quantitative soil age - Total microbial biomass	Sand dune substrate	110	0.053	11.962	0.016
	Other substrates	325	0.051	278.146	<0.001
Quantitative soil age - Soil respiration	Sand dune substrate	22	0.005	-0.023	0.745
	Other substrates	65	0.047	0.944	0.082
Quantitative soil age - Soil C:P	Sand dune substrate	110	0.057	20.324	<0.001
	Other substrates	325	0.530	331.578	<0.001

Supplementary Table 7 | Spearman correlation values ($P < 0.05$; N in Supplementary Table 3) associated with Fig. 10. See Fig. 1 for the location and acronyms of these chronosequences.

Ecosystem properties	JOR	BOS	BOV	AZ	CO	MI	ICE	ALPS	CAL	WA	CI	CH	TA	MEX	QL	HA
Chemical Index of Alteration		0.442	0.714	0.481	0.581					0.770		-0.405		0.400	-0.427	0.434
Total base cation reserve				-0.737	-0.617			-0.604		-0.849						
Fine texture				1.000	0.829	0.721					0.943				-0.943	
Soil pH	0.761	-0.799				-0.724	0.424	-0.843	-0.420	-0.954		-0.664			-0.488	-0.450
Soil total P -H2SO4	-0.799	-0.535			0.412	-0.642	0.565		-0.612	-0.923		0.527	0.318		-0.706	
Soil total P -HF	-0.745	-0.558		-0.853		-0.532		-0.404	-0.545	-0.908	-0.851	0.572				
Soil C:P ratio	0.605	0.768		0.481		0.858	-0.416	0.828		0.980	0.628	0.644	0.496		0.630	0.605
Soil N:P ratio	0.714	0.659		0.682		0.662	0.467	0.902	0.533	0.978	0.515	0.768	0.450		0.684	0.651
Soil C:N ratio	-0.659		-0.768			0.746	-0.498	-0.592		0.788						
Potential infiltration	-0.536					-0.668		0.577	-0.538		0.382					
Water holding capacity				0.768			-0.640	0.745	-0.565					0.397	-0.421	
Available P		0.582	-0.481	0.682	0.432	0.378		0.843	-0.886	-0.871	0.826	0.560				0.465
Available N	0.768						0.839	0.522	-0.783		0.466	0.587	0.613	0.441		
Soil C stocks		0.605		0.551		0.571		0.741		0.385	0.601	0.628	0.574	0.426		
Soil respiration				1.000							0.714					
Sugar degradation		0.648							0.463		0.723	0.416	0.465			
Chitin degradation			0.535						0.486	0.608	0.754	0.472				
P mineralization	-0.667	0.675	0.434	0.450		0.623				0.567	0.651	0.490				
Lignin degradation												-0.382				
Glucose respiration													-1.000			
Plant productivity	-1.000	0.949			-1.000	0.900	0.900	1.000	-0.900		0.886					
Wood production									-0.894			-0.928				
Proportion of forbs							0.659					0.857				
Proportion of grasses	-0.583					-0.730			0.914			0.573				
Proportion of shrubs				-0.637			0.761		-0.891							
Proportion of trees				0.777		0.493		0.702		0.702	0.663	0.512		0.572		
Total microbial biomass		0.698		0.636		0.606	0.620	0.832	0.384		0.739	0.605	0.768	0.502		
Biomass bacteria		0.714		0.690		0.615	0.643	0.828			0.739	0.628	0.752	0.577		
Biomass fungi		0.682		0.434		0.360		0.573	0.639	0.445	0.842	0.554	0.822			0.481
Fungi: bacteria ratio								-0.820	0.592	0.393	0.558	-0.793		-0.668	0.560	0.473
Arbuscular mycorrhizal fungi												0.673				0.458
Ectomycorrhizal fungi	0.456				-0.613	-0.379				-0.395		-0.371				

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Supplementary Methods 1 | List of papers used to obtain information for our meta-analytical approach.

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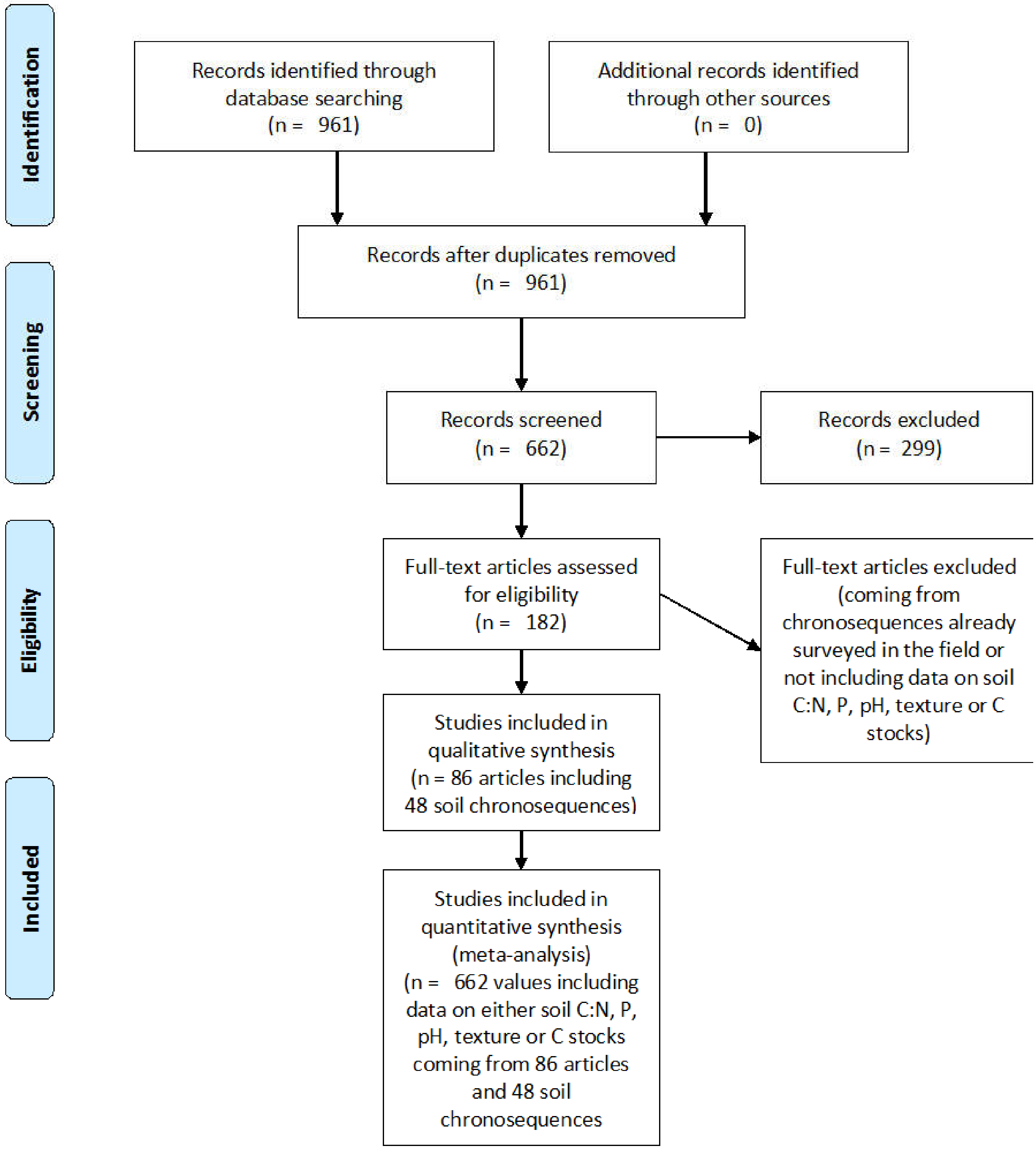
Supplementary Methods 2 | PRISMA 2009 Flow Diagram associated with our meta-analysis.

PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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