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Key Points:

- First evidence of peat initiation under late-20th century warming in a deglaciating montane valley in the Southern Hemisphere
- Consistent timing and direction of palaeoecological changes indicates catchment-scale ecological succession
- Climate-driven productivity increases may facilitate montane peatland development in suitable hydrological settings

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

R. E. Fewster,
richardefewster.ac@gmail.com

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Author Contributions:

Conceptualization: R. E. Fewster, G. T. Swindles, J. L. Carrivick, M. McKeown, J. L. Sutherland, F. Tweed
Formal analysis: R. E. Fewster, G. T. Swindles, J. L. Carrivick, M. Gałka, T. P. Roland, M. McKeown, J. L. Sutherland, F. Tweed, D. Mullan, C. Graham
Funding acquisition: G. T. Swindles, J. L. Carrivick
Writing – original draft: R. E. Fewster
Writing – review & editing: R. E. Fewster, G. T. Swindles, J. L. Carrivick, M. Gałka, T. P. Roland, M. McKeown, J. L. Sutherland, F. Tweed, D. Mullan, C. Graham, A. Gallego-Sala, P. J. Morris

Climate Warming and Deglaciation Drive New Peat Formation in the Southern Alps, Aotearoa/New Zealand

R. E. Fewster[1], G. T. Swindles[1,2], J. L. Carrivick[3], M. Gałka[4], T. P. Roland[5], M. McKeown[6], J. L. Sutherland[7], F. Tweed[8], D. Mullan[1], C. Graham[1], A. Gallego-Sala[5], and P. J. Morris[3]

[1]Geography and 14Chrono, School of Natural and Built Environment, Queen's University Belfast, Belfast, UK, [2]Ottawa Carleton Geoscience Centre and Department of Earth Sciences, Carleton University, Ottawa, ON, Canada, [3]School of Geography and water@Leeds, University of Leeds, Leeds, UK, [4]Department of Biogeography, Paleoecology and Nature Conservation, Faculty of Biology and Environmental Protection, University of Lodz, Łodz, Poland, [5]Geography, Faculty of Environment, Science and Economy, University of Exeter, Exeter, UK, [6]Department of Geography, University College Cork, Cork, Ireland, [7]School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, UK, [8]University of Staffordshire, Stoke-on-Trent, UK

Abstract Nascent peatlands represent an emerging, nature-based carbon sink in the global climate system. A warming climate and changing precipitation regime could drive peat initiation beyond the current latitudinal and altitudinal boundaries of the peatland bioclimatic envelope, through increases in plant productivity and moisture availability, with potential implications for global radiative forcing. However, contemporaneous observations of new peat formation remain scarce. We investigate peat initiation within the deglaciating Rob Roy valley in the Southern Alps, Aotearoa/New Zealand. We find that montane peats have developed across the head of the valley since ~1949 C.E., coinciding with regional climate warming and glacial retreat. Further, we identify a common ecological succession, characterized by a rise in brown mosses (mainly *Bryum*) beginning around ~1963 C.E. Our findings indicate the potential for wider peat expansion in increasingly warm and wet montane landscapes. However, further bioclimatic modeling is required to elucidate where future peatland developments may occur.

Plain Language Summary Peat, a highly organic soil, forms where plant matter is prevented from fully decomposing, forming an important carbon sink. 20th-century climate change appears to have made mountainous regions more favorable for new peat formation, because rising temperatures have enhanced plant growth and glacial retreat has exposed ice-free areas for ecological colonization. However, evidence of new peat forming in response to recent climate change is limited in the Southern hemisphere. We investigated peat formation in a deglaciating valley in the Southern Alps, Aotearoa/New Zealand. Our findings show that peat has been accumulating in the upper valley since ~1949 C.E., during a period of steady warming. From ~1963 C.E., plant communities across the valley have consistently shifted from herbaceous plants to mosses. Our results suggest that warming and wetting climates may enable future peat formation in mountainous regions, although further research is needed to determine the plausible extent of any future expansion.

1. Introduction

Global peatlands are an important carbon (C) store, containing >20% (~610 Gt) of the global soil organic carbon pool (Köchy et al., 2015; Page et al., 2011), despite covering only ~3% of the Earth's terrestrial surface (~4.2 million km^2) (Xu et al., 2018). Peatlands have developed within a constrained range of climatic conditions, known as a bioclimate envelope (Morris et al., 2018). Peatlands form under a wide range of mean annual temperatures, but their distribution is also limited by precipitation and growing degree days (Fewster et al., 2020, 2022; Gallego-Sala & Colin Prentice, 2013; Yu et al., 2009). This bioclimate envelope, and thus global peatland distribution, has shifted throughout the Holocene (last ~11,750 years) due to deglaciation (Gorham et al., 2007) and postglacial climate change (Morris et al., 2018). Peat accumulation in high latitude and montane environments has been limited in part by low temperatures, which inhibit plant productivity. However, anthropogenic greenhouse gas release has increased global temperatures by ~1.1°C (1850–1900 to 2011–2020 C.E.; Lee et al., 2023), with faster warming occurring in mountainous and Arctic regions (e.g., Rantanen et al., 2022; Wang et al., 2014). Rising temperatures in montane regions have been associated with widespread greening (e.g., Carlson et al., 2017; Rumpf et al., 2022), shifts from snow to rainfall (e.g., Li et al., 2020; Serquet et al., 2011) and changes in the timing and magnitude of snow and glacier melt (e.g., Klein et al., 2016; Vorkauf et al., 2021). These climate-driven changes may be favorable for new peat accumulation, because warmer, wetter climates stimulate plant growth, while glacial retreat exposes new environments for ecological colonization. Thus, the peatland bioclimate envelope may now be shifting into previously unsuitable landscapes. Any new peat formation may increase the global peatland C sink and partially offset decomposition losses from relict peatlands that now exist under unsuitable climates for peat growth (Gallego-Sala & Colin Prentice, 2013). However, observational evidence of recent peat formation is limited, particularly in the Southern Hemisphere, meaning that it is unclear how readily peatland extents might expand under warming climates.

The Southern Alps, Aotearoa/New Zealand, is a region undergoing rapid environmental changes in response to anthropogenic climate change. Glaciers presently occupy ∼1,021 km^2 of the Southern Alps (Carrivick et al., 2020), but several glaciers have recently experienced rapid mass loss, including the Franz Josef and Fox glaciers (e.g., Anderson et al., 2006; Purdie et al., 2014), which have acted as barometers of climate change for the Southern Hemisphere. Since the Little Ice Age (LIA), ice volume loss across the Southern Alps has been up to six times greater than in other parts of the Southern mid-latitudes (Carrivick et al., 2020). This has resulted in rapid, proglacial landscape and habitat changes, including lake formation (Carrivick et al., 2022), alterations to river and fluvial sediment regimes (Carrivick & Tweed, 2021), and aquatic habitat conditioning (e.g., Fell et al., 2017). Recent climate change and continued deglaciation in the Southern Alps interior may have provided new, environmentally-plausible locations for peat initiation, which have not yet been accounted for in regional assessments and global modeling of peatland extents and soil organic carbon stocks. Montane climates in New Zealand are generally favorable for peat development, with high rainfall, low sunshine hours and low evaporation rates, although cool summers have often resulted in slow accumulation rates (McGlone, 2009). Typical montane peatlands in New Zealand include shallow sloping fens, bogs, and cushion bogs (McGlone, 2009). Peatlands are common in the neighboring, unglaciated district of Central Otago (Dickinson et al., 2002; McGlone et al., 1997) and peat has accumulated at the northwestern fringes of the Southern Alps since ∼9,337 years B.P. (McGlone & Basher, 2012). However, peatland extents in the Southern Alps interior likely remain underestimated, because national assessments are often based on satellite mapping (e.g., Ausseil et al., 2008; Dymond et al., 2021) and many montane peatlands are small (<0.5 ha) and lack well-defined boundaries. New field-based studies are urgently needed to determine the location, timing and developmental pathways of emerging peatlands in this rapidly warming region. Establishing a case study of early peat development under anthropogenic climate change may provide useful insights into peatland dynamics in other montane and high latitude regions where similarly rapid bioclimatic changes are occurring.

In December 2018, we identified patches of peat-forming vegetation in a deglaciating valley in the Southern Alps of Aotearoa/New Zealand. Subsequent probing identified shallow underlying peat soils. In this study, we use a palaeoecological approach to investigate the timing of peat initiation and patterns of ecological succession in these poorly understood montane ecosystems.

2. Study Site and Methods

2.1. Study Site and Sampling

Our study site is located at 761 m above sea level (a.s.l.), near the upper lookout of the Rob Roy Track in the Mount Aspiring National Park (Table S1 in Supporting Information S1; Figure 1). This track terminates in front of Rob Roy hanging glacier, which is retreating slowly northwards toward Rob Roy Peak (2644 m a.s.l.) and thinning, now only being sustained by avalanching. Local vegetation, soil cover, and gullying suggest that the Rob Roy glacier once terminated at our study site during the LIA (∼1450–1800 C.E.), while mapping of glacier outlines shows further retreat from 1978 C.E. to 2019 C.E. (Carrivick et al., 2020) (Figures 2a–2c).

The Rob Roy Stream drains the valley, flowing from a 500 m stretch of gravel outwash sediments at the toe of the glacier into a narrow step-pool channel that feeds the western Matukituki River. The altitudinal treeline (primarily native *Nothofagus spp*.) varies between 720 and 950 m a.s.l., due to hillslope mass movements near the Rob Roy Stream (Cadbury et al., 2011). Above the treeline, low-lying vascular plants grow atop scree, glacially-transported gravel, debris flow deposits and/or thin minerogenic soils (Radford et al., 2010). Previous studies have researched the hydroecology and thermodynamics of the Rob Roy Stream (Cadbury et al., 2008, 2011; Radford et al., 2010). Observations of geomorphological processes, deglaciation, vegetation regrowth and climate warming in this valley indicated potential for recent peat initiation. Our subsequent probing identified three

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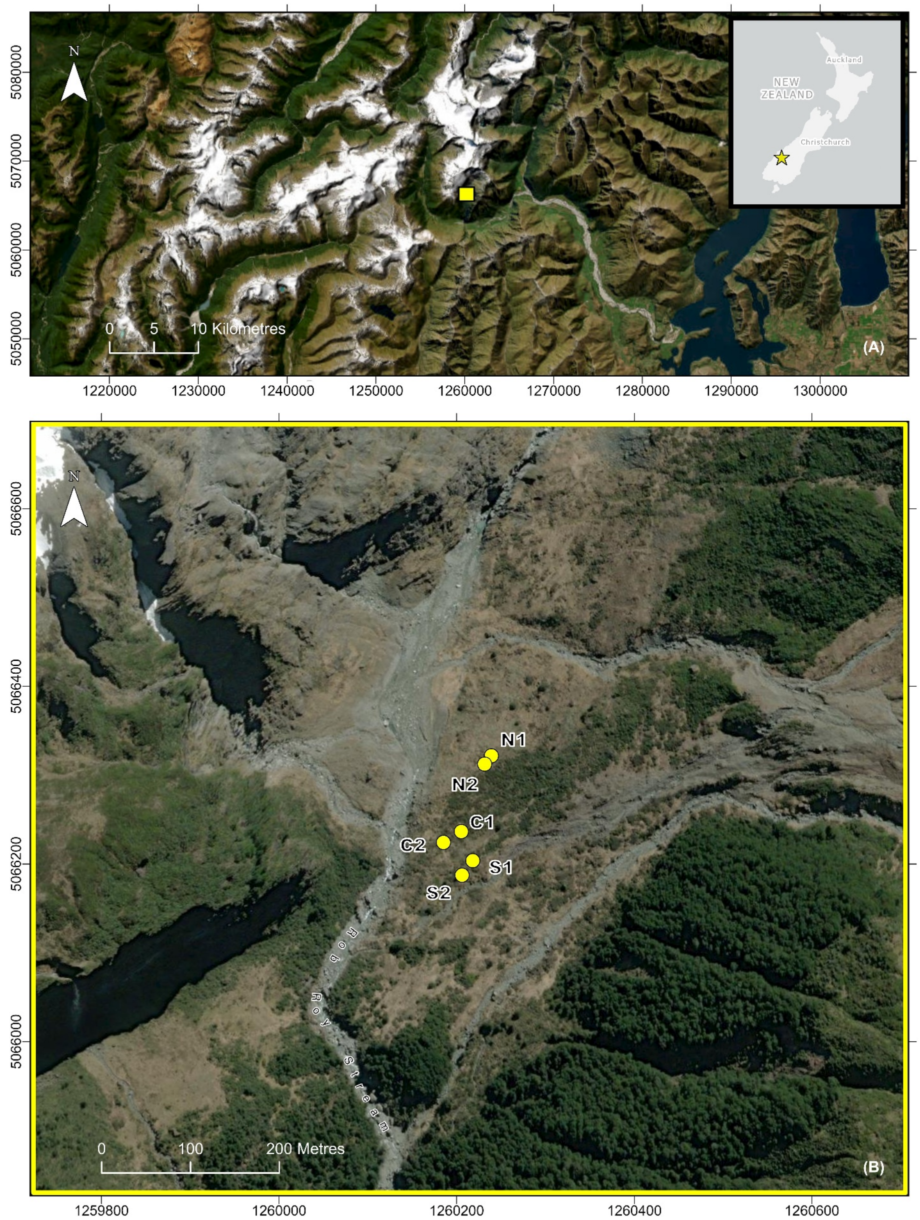

Figure 1. Maps showing: (a) our site location in the Southern Alps, Aotearoa/New Zealand; and (b) our sampling locations in the Rob Roy valley. Projection: New Zealand Transverse Mercator [NZTM2000]. Imagery from MAXAR and ESRI (2024).

disconnected peat patches, each located near a small watercourse, across a 15 m elevation gradient in the upper valley (Figure 1).

We sampled duplicate monoliths from the center of each peat patch ($n = 6$) to investigate local-scale heterogeneity in montane peat-forming processes (Table S1 in Supporting Information S1). Surface vegetation included mosses (e.g., *Bryum laevigatum*) and vascular plants (e.g., *Dracophyllum longifolium*, *Dolichoglottis lyallii*, *Celmisia gracilenta*, *Blechnum penna-marina* ssp. *alpina*, *Olearia nummulariifolia*, and *Gaultheria crassa*). We cut square-section monoliths to the peat base using a spade and serrated breadknife, dug a small trench immediately adjacent to the peat block, and sliced underneath using a pallet knife, allowing us to carefully lift the monolith. We packaged each peat monolith in clingfilm for transport to the University of Leeds, UK, where they were stored at ~4°C. We recorded pH at each sampling location using a calibrated field meter.

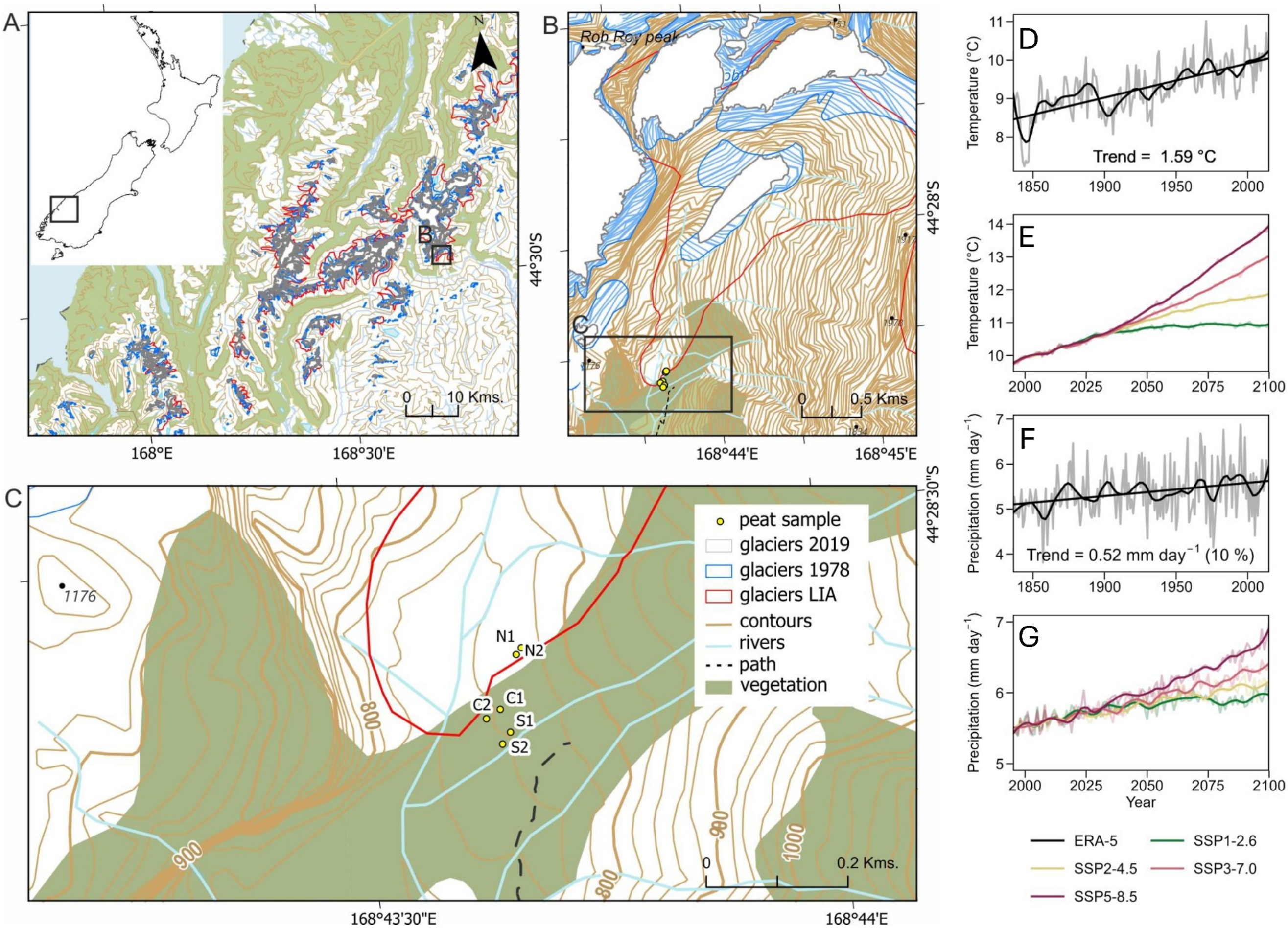

Figure 2. Late-Holocene environmental change in our study region. Glacial outline data at: (a) regional, (b) landscape, and (c) local scales for the LIA (~1450–~1800 C.E.), 1978 C.E. and 2019 C.E. (adapted from Carrivick et al. (2020)). Panels (d–g) present historical (1836–2015 C.E.) and projected (2015–2100 C.E.) mean monthly temperature (°C) and precipitation (mm day^{-1}) trends for our study region (see methods for details).

2.2. Climate Data

To characterize historical climate change at our site, we downloaded monthly temperature and precipitation data for the period 1836–2015 C.E. from the NOAA/CIRES/DOE 20th Century Reanalysis V3 data set (Compo et al., 2011; Slivinski et al., 2019) from KNMI Climate Explorer (https://climexp.knmi.nl/). We analyzed data for the 1° latitude × 1° longitude spatial domain overlying the study area (−43.5 to −44.5°N and 168.5 to 169.5°E).

To establish possible pathways of future climate change, we analyzed the Coupled Model Intercomparison Project 6 (CMIP6) mean for temperature and precipitation at the same study area for the period 1995–2100 C.E.. These data were downloaded from KNMI Climate Explorer for four shared socioeconomic pathway (SSP) scenarios: SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–4.5 (Riahi et al., 2017). Climate scenarios were bias corrected and spatially downscaled to the same spatial resolution of the reanalysis data set using the change factor method (e.g., Hawkins et al., 2013), by subtracting CMIP6 mean data for 1995–2014 C.E. from reanalysis data for the same period (1995–2014 C.E.), and then adding the difference (change factor) to CMIP6 mean data for 2015–2100 C.E. (on a monthly basis).

To assess the modern climatic conditions that facilitated peat initiation, we calculated mean annual temperature (MAT; °C) and total annual precipitation (APREC; mm yr^{-1}) values from the historical monthly means for the 30-year period surrounding peat initiation at our study site (1945–1974 C.E.; see Results below). We also calculated equivalent values for each SSP scenario for the period 2091–2100 C.E.. In Figure S1 in Supporting

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Information S1, we compare the modern and projected climate space of our site to published data describing the palaeo-climate space of peatland initiation globally (n = 1,097 sites) (Morris et al., 2018).

2.3. Subsampling and Peat Properties

In the laboratory, we subsampled each peat monolith at contiguous 1 cm intervals using a stainless-steel knife, rinsed between cuts with deionized water to avoid contamination between samples. For each depth, we analyzed 1 cm^3 subsamples for dry bulk density (g cm^{-3}), moisture content (%), and organic matter content (%) via loss-on-ignition, following Chambers et al. (2011).

2.4. Plant Macrofossils

We analyzed plant macrofossil compositions at 1 cm resolution for each monolith using a stereoscopic microscope, following Gałka et al. (2017). We recorded quantities of the primary peat-forming components (e.g., mosses, liverworts and vascular plants) as proportions of the total sample volume (%) and calculated absolute counts for fruits and seeds only. We present plant macrofossil proportions (%) in Figure 3, while full macrofossil diagrams (including counts of seeds and fruits) are presented in Figures S8–S13 in Supporting Information S1.

2.5. Chronology

We define basal peat to be any soils with >30% organic matter (e.g., Joosten and Clarke (2002)) to a depth of at least 0.1 m (Lourenco et al., 2022). While we acknowledge that this depth is shallower than some traditional peat definitions (Lourenco et al., 2022), we believe this is appropriate for our study of the earliest developmental phases of emerging peat patches, which have not had sufficient time to accumulate thick peat layers.

To establish robust chronologies for each peat monolith, we constructed Bayesian age-depth models from ^{210}Pb profiles and radiocarbon (^{14}C) dating in Plum v.0.4.0 (Aquino-López et al., 2018) in R v.4.3.2 (R Core Team, 2022). To begin, we ^{14}C dated the deepest available peat sample, then added additional ^{14}C dates to further constrain our chronologies based on palaeoecological profiles and peat properties data. We primarily ^{14}C dated plant macrofossils, and dated one bulk peat sample where suitable, intact plant material was unavailable (see Table S2 in Supporting Information S1 for details). All ^{14}C dating was conducted using accelerated mass spectrometry (AMS) at the André E. Lalonde AMS Laboratory at the University of Ottawa. We calibrated all ^{14}C dates using either the IntCal20 radiocarbon calibration curve (Reimer et al., 2020) or the SH1-2 post-bomb calibration curve (Hua et al., 2022). We also analyzed ^{210}Pb in continuous 1 cm^3 peat subsamples spanning the full length of each monolith using alpha spectrometry at the University of Exeter, following Estop-Aragonés et al. (2018). We established calibrated ages for each peat sample from the probability estimates generated by our Bayesian age-depth models, and report weighted mean ages hereafter, unless otherwise specified. Prior settings and full modeled age estimates for each monolith are presented in Figures S2–S7 in Supporting Information S1.

3. Results and Discussion

Peat initiation and plant macrofossil accumulation began between ~1949 and ~1973 cal. yr C.E. across the deglaciating Rob Roy valley in the Southern Alps, Aotearoa/New Zealand. Regional climatic conditions at this time (MAT = 9.7°C; APREC = 1984 mm yr^{-1}; averaging period: 1945–1974 C.E.) fell well within the palaeo-climate envelope for global peatland initiation (Morris et al., 2018) (Figure S1 in Supporting Information S1). Our findings indicate a continuation of new peatland initiation in Aotearoa/New Zealand, which has been ongoing since ~14,000 cal. yr B.P. (McGlone, 2009). Similar evidence of 20th-century peat initiation has been observed in warming and wetting circum-Arctic regions, including subarctic Canada (Piilo et al., 2019) and Svalbard, Norway (Juselius et al., 2022). Peat moss banks in Antarctica have also evidenced increased productivity and vertical accumulation in response to late-20th century warming (Amesbury et al., 2017; Yu et al., 2016), although these Antarctic peats first formed as early as ~2,750 cal. yr BP (Loisel et al., 2017). To our knowledge, our study has recorded the most recent peat initiation dates for any montane peatlands in the Southern Hemisphere.

Modeled mean ages indicate that peat developed earliest at locations N2 and C2 (both ~1949 cal. yr C.E.), followed by C1 (~1957 cal. yr C.E.), N1 (~1958 cal. yr C.E.), S1 (~1959 cal. yr C.E.) and most recently at S2 (~1973 cal. yr C.E.) (Table S2 and Figures S2–S7 in Supporting Information S1). In basal peat samples, organic

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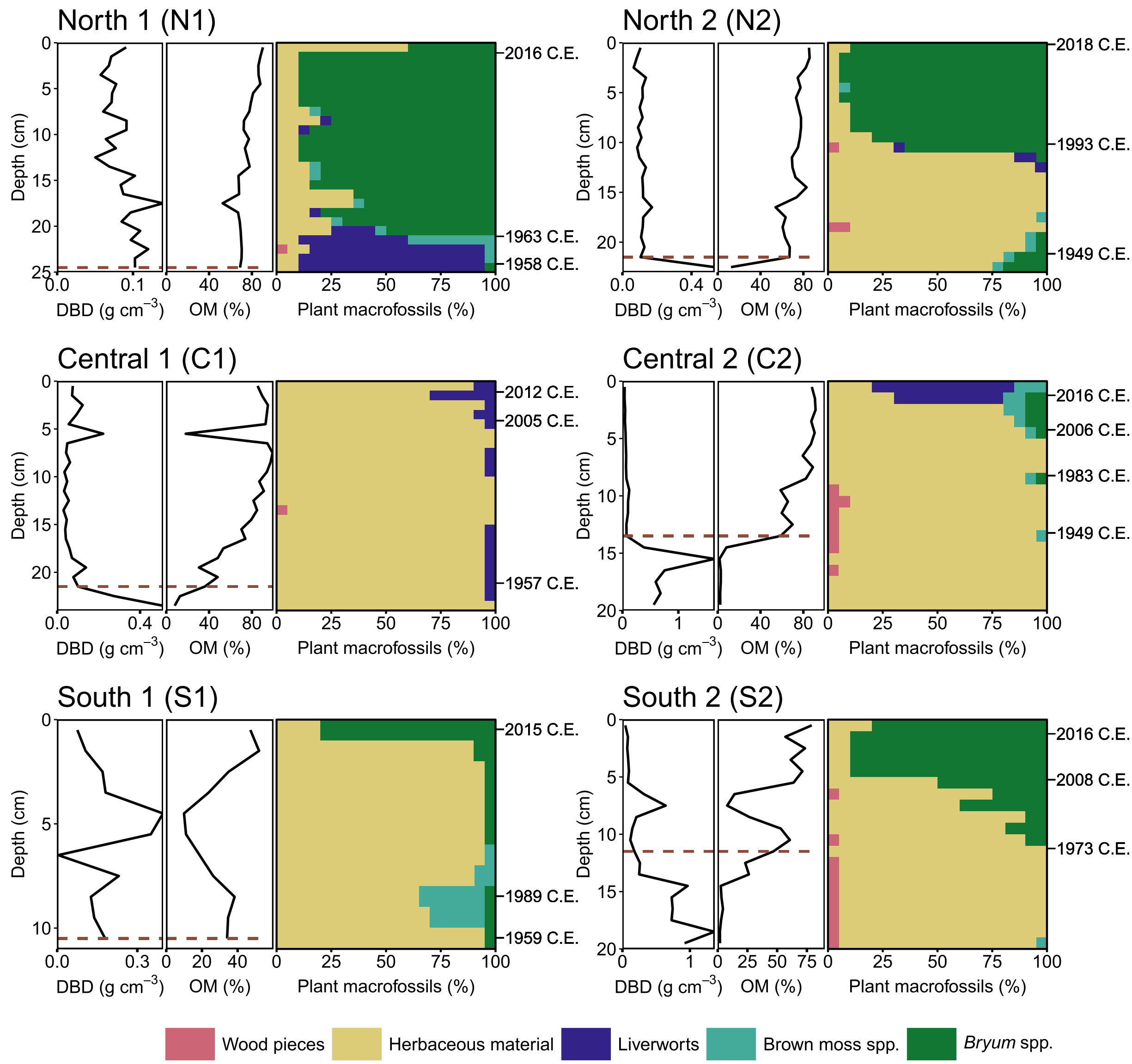

Figure 3. Summarized palaeoecological information. Line graphs show dry bulk density (DBD; g cm^{-3}) and organic matter content via loss on ignition (OM; %) (line graphs). Dashed line indicates interpreted depths of basal peat (see methods for details). Stacked bar charts show percentage composition of the major peat-forming components. For detailed palaeoecological diagrams see Figures S8–S13 in Supporting Information S1.

matter content was highest in the N1 and N2 monoliths (67% and 69%), while the basal samples of C1 and S1 contained a lower organic matter content that was closer to our threshold for peat soils (35% and 34%, respectively). Our interpretations of the peat-mineral boundary were supported by low dry bulk density values in all basal samples (0.07–0.18 g cm^{-3}), which is well below the typical upper limits for peat soils, for example, 0.3 g cm^{-3} (Morris et al., 2022). Indeed, deeper, non-peat samples in monoliths N2, C1, C2, and S2 substantially exceeded this dry bulk density threshold (Figure 3), while monoliths N1 and S1 were inferred to be entirely composed of peat, having formed directly on a matrix of superficial glaci-fluvial silts and sands, moraine gravel and boulders, hillslope scree and debris flow deposits. Our age-depth models indicated varying rates of recent peat and C accumulation, with thicker peat deposits at N1 (25 cm), N2 and C1 (both 22 cm) and shallower peats down-valley at C2, S1 and S2 (14, 11 and 12 cm, respectively). However, we do not interpret patterns of peat accumulation further, because of the difficulties in untangling genuine temporal variability in individual records from incomplete and secondary decomposition (see Young et al., 2021).

Our plant macrofossil analyses suggest a consistency in ecological succession across our sampling locations toward *Bryum* mosses and/or liverworts (Figure 3; Figures S8–S13 in Supporting Information S1). In five of the six monoliths (N2, C1, C2, S1 and S2), herbaceous leaves and roots comprised the primary peat-forming vegetation in early peat layers (55%–100% composition). Moderate proportions of brown mosses developed for a temporary period after peat formation in monoliths N1 and S2. Conversely, in the northernmost site, N1, early peats are dominated by liverworts (≥80%), with only minor proportions (≤10%) of herbaceous material recorded in this profile until present, when abundances increased to 60%. Because of the macrofossil composition of these samples, we infer that a wet, nutrient-rich, minerotrophic environment supported the early stages of peat formation. In all monoliths, counts of Apiaceae seeds increase during, or shortly after, the primary palaeoecological transitions. In monoliths N1 and N2, *Bryum* cf. *leavigatum* became dominant from ∼1967 cal. yr C.E. and ∼1993 cal. yr C.E., respectively, with stable proportions of 60%–90% until present. Equivalent, recent increases in *Bryum* mosses occurred in S1 and S2 after ∼2011 cal. yr C.E., alongside increases in organic matter content and reductions to dry bulk density. By contrast, *Bryum* mosses were broadly absent from the C1 and C2 records, which instead indicated increased abundances of liverworts (C1 and C2) and brown mosses (C2 only) after ∼2012 cal. yr C.E., a pattern which is not reflected in our other monoliths. *Bryum* mosses and liverworts are resilient, pioneer plants known to thrive on deglaciated substrates where competition from vascular plants is limited (Wietrzyk-Pełka et al., 2020), and indicate that conditions are still minerotrophic (Van der Putten et al., 2008, 2012), an assertion supported by in-field pH measurements of 6.38–6.70 at our sampling locations (Table S1 in Supporting Information S1). Similar increases in *Bryum* and liverwort abundance have previously been recorded during the early developmental stages of some older subantarctic peatlands (e.g., Van der Putten et al., 2008, 2012). However, decay rates of liverworts vary widely (Lang et al., 2009) and some liverwort remains may eventually fully decompose and not be incorporated into deeper, older peats (Svensson, 1986). Therefore, in the long term, peat layers formed from moss, herbaceous and woody macrofossils may preferentially persist (Figure 3), because these plant litter are generally more resilient to decomposition.

The absence of *Sphagnum* macrofossils in our monoliths is likely due to the distinct ecohydrological conditions of New Zealand peatlands, which differ substantially from Northern Hemisphere bogs. Unlike their Northern counterparts, montane cushion bogs of Aotearoa/New Zealand do not typically support *Sphagnum* during their natural succession. More commonly, cushion bogs are dominated by graminoids, herbs, subshrubs and restiads (McGlone, 2009; McGlone et al., 1997). McGlone and Wilmshurst (1999) have suggested that *Sphagnum* dominance in some lower-lying, South Island bogs may be a recent phenomenon, driven by anthropogenic influences. For example, deforestation through Māori burning practices and European logging has likely altered the hydrology of many catchments, increasing water flow to lower-elevation peatlands and creating wetter conditions favorable to *Sphagnum* proliferation (McGlone, 2009). Recent research by McKeown et al. (2024) also suggests that *Sphagnum* dominance in some Aotearoa/New Zealand peatlands may not reflect natural conditions but rather anthropogenic alteration. This highlights the unique dynamics of Aotearoa/New Zealand's peatland ecosystems and underscores the need for region-specific approaches to ecological assessments, avoiding the assumption that these emerging peatlands will follow Northern Hemisphere models of ecological succession.

Our observations of 20th-century peat initiation and early ecological succession in the Rob Roy valley coincides with a period of almost linear warming, with MAT increasing by >1.5°C during the post-industrial period and by 0.46°C during the 30-year period from 1986–1995 C.E. to 2006–2015 C.E. (Figure 2d). Concurrent precipitation increases have improved the climatic suitability of our study area for new peat initiation (Figure 2f). Further increases in temperature and precipitation have been projected for this region by 2100 C.E., even under a "best-case" climate-mitigation scenario (SSP1-2.6) (Figures 2e and 2g). Under a "worst-case" no-mitigation scenario (SSP5-8.5), climatic conditions at our site are projected to shift toward the limits of the palaeo-climate space for global peatland initiation, but would still remain suitable by 2091–2100 C.E. (Morris et al., 2018) (Figure S1 in Supporting Information S1). Although recent, temperature-driven increases in plant productivity have driven advancement of altitudinal treelines in alpine regions worldwide (e.g., Harsch et al., 2009), treelines in the Southern Alps have instead exhibited remarkable stability (e.g., Cullen et al., 2001; Hansson et al., 2023). Nonetheless, late-Holocene climate change and subsequent deglaciation seem to have stimulated recent peat initiation in this valley. Warming growing seasons exert a primary control on peat initiation (Morris et al., 2018), while ice retreat in this valley has exposed a pristine, unoccupied terrain for ecological colonization and subsequent peat growth. Similar environmental changes appear to have accelerated the growth of emerging peat patches in Arctic Alaska (Cleary et al., 2024; Gałka et al., 2018, 2023; Taylor et al., 2019), while satellite observations indicate that sustained greening and moss expansion is ongoing across warming regions of the Arctic (e.g., Crichton et al., 2022; Grimes et al., 2024; Karlsen et al., 2024) and Antarctic (Roland et al., 2024). Holocene records indicate that peat development in deglaciated landscapes of North America and northern Europe has commonly lagged ice retreat by several millennia (Gorham et al., 2007; Ruppel et al., 2013). However, evidence of LIA moraines within meters of our sampling locations (Figures 2a–2c; Carrivick et al., 2020), coupled with the late 20th-century timing of our basal peat samples (Figure 1; Table S2 in Supporting Information S1), suggest that any postglacial lag in peat development in the Rob Roy valley has been by no more than a few centuries.

In addition to sufficient warmth for plant productivity, sustained peat accumulation requires a landscape setting with a persistent excess of surface moisture, resulting from excess precipitation and/or a slowly draining substrate, which inhibits the complete decomposition of plant litter (e.g., Clymo, 1984). Basal peats at our sites were primarily composed of herbaceous taxa that thrive in moist or wet minerotrophic conditions (Figure 3). Our studied peat patches also formed in similar topographical locations, particularly undisturbed, west-facing, gentle slopes of no more than 15° with small streams that receive a regular supply of meltwater, either from the northward Rob Roy glacier or adjacent snowpacks on the eastern peaks (Figure 1). Peat was absent in the intervening and upslope areas from our sampling locations, as well as the steep cliffs along the western valley side and along the Rob Roy stream where intense geomorphological action is ongoing, resulting in bank erosion, instability and subsidence. Topographical and hydrological constraints on peat growth may also explain why peat patches do not currently extend as far upslope as the present altitudinal treeline (Figure 1). It is possible that the underlying geological matrix of silt, gravel and rocks across much of this valley is too porous to retain sufficient moisture to support peat growth from precipitation alone, without additional inputs from snow and glacier melt. The observed concentration of these shallow peats around meltwater streams places their long-term resilience in doubt if the Rob Roy glacier continues to retreat and ultimately disappears. However, projected future increases in precipitation (Figure 2d), alongside shifts from snow to rainfall, may partially overcome this hydrological constraint on peat development by increasing surface wetness in certain parts of the valley. Further bioclimatic modeling, supported by high-resolution geological and topographical data sets, is now recommended to elucidate how projected climate change may impact the extent of potential peat-forming areas in this montane environment.

The newly formed montane peats we have identified in Aotearoa/New Zealand represent a small, albeit growing, natural C sink that has not yet been accounted for in large-scale peatland maps (e.g., Xu et al., 2018) or land-surface model projections (e.g., Hardouin et al., 2024; Müller & Joos, 2021). It is therefore possible that coarse-scale model projections presently underestimate the capacity for warming and deglaciating montane regions to sustain new peat growth and thus enhanced C sequestration. Continued expansion of these, and other, montane peat patches could partially offset greenhouse gas losses from the extensive anthropogenic degradation of lowland peatlands, which have declined in areal extent by ~90% in Aotearoa/New Zealand since European settlement (Ausseil et al., 2008; McGlone, 2009). Indeed, more-developed montane peatlands in Aotearoa/New Zealand have been found to reach substantial thicknesses (>2 m), even if their areal extent remains small (e.g., McGlone, 2009; McGlone et al., 1995).

The easy accessibility of our site, located at the northern end of the Rob Roy Glacier track, makes it a promising case study for real-time monitoring of the response of nascent peats to glacial retreat and climate warming. Additionally, future studies could determine rates of lateral peat expansion at this site using well-dated, core-based transects from the peat margins (e.g., Juselius-Rajamäki et al., 2023). Further surveying is also now needed to elucidate the wider spatial context of our small-scale case study, which has considered six peat monoliths in a single deglaciating valley. Remote sensing techniques could scale-up the identification of plausible areas for recent peat initiation by assessing changes in surface moisture and vegetation productivity (e.g., Crichton et al., 2022). To aid this effort, we propose a criteria-based framework for identifying potentially suitable locations for montane peat initiation, based on our palaeoecological and field-based observations. Our findings suggest that peat can initiate in montane environments that exhibit: (a) areas susceptible to ecological colonization, such as bare mineral substrates or postglacial melt ponds (as found in deglaciating valleys); (b) suitable climatic conditions for sustained plant growth, including temperature and precipitation; and (c) saturated surface conditions, arising from some combination of gently sloping terrain, poorly drained substrate, presence of freshwater streams and/or meltwater. We recommend that future studies employ this framework to identify possible locations for new peat initiation in other, similar montane regions. As shown in our study, combining such predictions with ground-truthed observations and palaeoecological analyses of early ecological succession can provide new insights for constraining model representations of the dynamics of peatland development under a changing climate.

4. Conclusions

Our study presents, to our knowledge, the first evidence of new montane peat initiation occurring under 20th-century climate change in the Southern Hemisphere. Our radiometric dating of basal peat samples indicates that peat initiation in the deglaciating Rob Roy valley in the Southern Alps, Aotearoa/New Zealand began at ∼1949 cal. yr C.E. and has continued until at least ∼1973 cal. yr C.E.. Our palaeoecological analysis indicates that these nascent peats have undergone a consistent trajectory of ecological succession, with increasing abundances of *Bryum* moss evident in five of the six monoliths. Continued expansion of these emerging peat patches may increase the C-sink capacity of global peatlands, thereby enhancing their overall climate mitigation effect. However, the apparent dependence of these shallow peats on meltwater availability, coupled with ambiguity regarding the extent of suitable niches for broader montane peat expansion, makes the wider spatial implications of our findings uncertain. Further observational and palaeoecological research is therefore needed to identify similar examples of recent and ongoing peat formation in other montane regions to improve understanding of peat initiation dynamics at the altitudinal boundaries of their bioclimatic envelope. The full geographic extent of new peat formation driven by recent climate change remains unknown, as does any potential impact on the global C cycle.

Data Availability Statement

The palaeoecological data underlying this research are available at Zenodo via https://zenodo.org/records/14177780 (Fewster, 2025).

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