communications
earth & environment

ARTICLE

https://doi.org/10.1038/s43247-023-00977-1 OPEN

Abrupt, climate-induced increase in wildfires in British Columbia since the mid-2000s

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In the province of British Columbia, Canada, four of the most severe wildfire seasons of the last century occurred in the past 7 years: 2017, 2018, 2021, and 2023. To investigate trends in wildfire activity and fire-conducive climate, we conducted an analysis of mapped wildfire perimeters and annual climate data for the period of 1919–2021. Results show that after a century-long decline, fire activity increased from 2005 onwards, coinciding with a sharp reversal in the wetting trend of the 20th century. Even as precipitation levels remain high, moisture deficits have increased due to rapid warming and increased evaporative demand. Bottom-up factors further influence fire activity, as the legacy of past wildfires, insect outbreaks, and land-use practices continually influence fire regimes. The compound effects of climate-induced moisture changes and altered fuels now force British Columbians to confront the harsh reality of more frequent years of intense and prolonged wildfire activity.

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The province of British Columbia (BC), Canada, has experienced its four most severe wildfire seasons (2017, 2018, 2021, and 2023) of the last half-century during the past 7 years, all of which were marked by weather extremes. For example, in the summer of 2021 a heat dome that covered most of western Canada shattered temperature records and fueled wildfires from central Canada to the Pacific Coast[1]. The warmest temperature ever recorded north of the 45th parallel (49.6 °C) occurred in the small town of Lytton, BC, on June 29, 2021; the next day, a fast-moving fire that started on the edge of the town spread through and destroyed most of the community in minutes. Dozens of synchronous ignitions from lightning and people in early July led to fire-suppression resources being fully committed. As fire-conducive weather persisted, some uncontained wildfires burned for months, producing dense smoke that covered central and southern BC and spread eastward to central Canada and southward to some northern and midwestern states of the conterminous USA. Some wildfires exhibited extreme behavior, such as fire whirls, as well as the production of lightning from the pyrocumulus clouds that ignited new wildfires[2]. Many homes were lost across BC, and a record number (168) of evacuation orders were issued[3]. First responders grappled with chronic stress and exhaustion. Although the historic events in 2021 came soon after the record-breaking years of 2017 and 2018, many people in and outside of BC were still surprised at their severity. No more than 2 years later, in 2023, wildfires have already burned 1.75 Mha in BC (as of August 24), breaking the previous area-burned record and registering its largest-ever wildfire (Donnie Creek fire, ~550,000 ha).

Compared to other parts of western Canada that are situated mostly in the boreal biome, fire activity in BC in the 20th century was considered low or moderate, with very large wildfires (>50,000 ha) being relatively infrequent. While climate and weather are undoubtedly the major drivers of fire activity in BC, several wide-ranging anthropogenic factors also come into play, notably land-use change and fire-management policies focused on fire suppression[4–6]. These factors, in combination with climate, have shaped wildfire trends over the past century. In the early 20th century, pronounced droughts and numerous human-ignited fires due predominantly to logging, mining, land clearing and railroad construction led to a wildfire regime characterized by numerous fires of relatively small size, on average[7,8]. Since the 1950s, the number and area burned of wildfires had been steadily decreasing in the province until ~2000 (277.7 fires ≥20 ha/year and 212,000 ha/year during 1919–1950 vs 116.8 fires and 89,000 ha/year during 1951–2000), a consequence of a cooler and wetter climatic pattern mid-century[9] and increasing fire suppression effort and effectiveness. Contrasting with this 20th-century decline in fire activity, studies investigating future fire potential unanimously project substantial increases in fire activity in BC over the 21st century[10,11]. That is, assuming no change in current fire management and land use, the projected warming and drying of the climate would invariably reverse the historical decreasing trend in fire activity and cause a marked amplification of annual area burned rates towards the middle of the century. The recent surge in fire activity is thus, in a sense, unsurprising. What is surprising, however, is the early onset of the increase in wildfire activity around the year 2000—decades earlier than anticipated—and the sheer magnitude of fire-season severity (e.g., three of the past 7 years experienced >1 Mha or >1% of the land area burned; compared to only three wildfire seasons from 1919 to 2016 surpassing 0.5 Mha).

Across its 94.5 Mha (more than twice the area of California), the diverse relief and geology of BC, combined with steep climatic gradients, results in staggering diversity in biological communities and disturbance regimes (Supplementary Fig. 1). With a population of approximately five million, densities of people and infrastructure (e.g., permanent roads) are low in much of BC, with most of the large urban centres on the south coast. Its 60 Mha of forests and other natural vegetation types (i.e., grasslands, shrublands, and woodlands) have shaped the area's social, cultural, and economic identity. BC's forests essentially span all of the moisture spectrum, from temperate rainforests to high-desert woodlands; approx. 15% are considered dry, 31% wet, and 54% mesic[12]. Broadly, BC can be stratified in three large zones, considered in this study (Fig. 1): a Central zone covering a large inland area in the southern two-thirds of the province, a Coastal zone forming a broad band of marine-influenced ecosystems bordering the Pacific Ocean, and a Northern zone that represents a transition to northern forests. All zones are heavily forested but

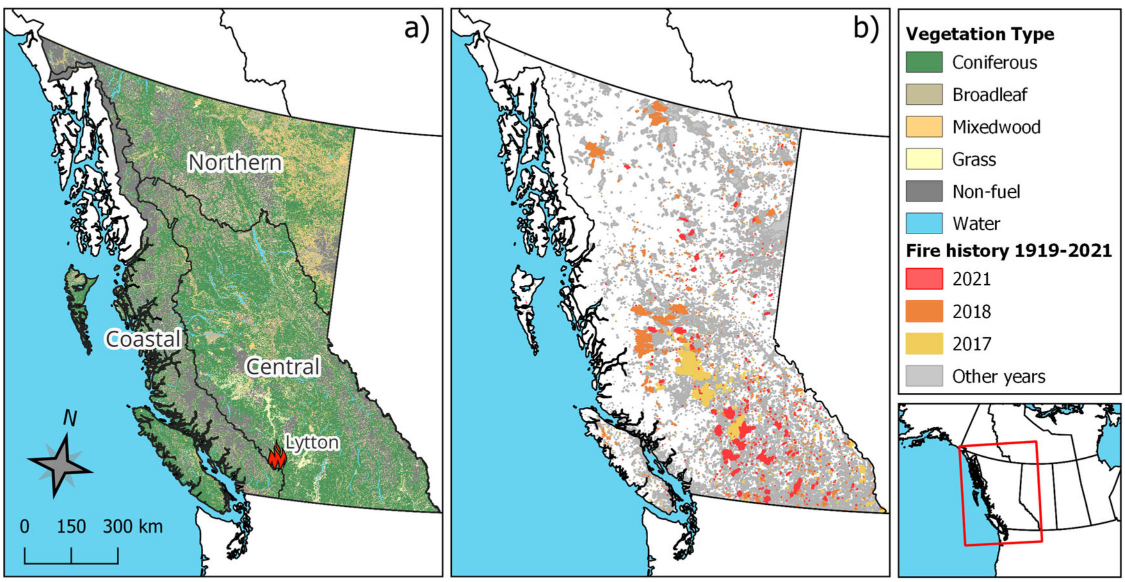

Fig. 1 The study area, British Columbia, including three nested zones (Central, Coastal and Northern). Vegetation type (**a**) from 2019 Risk Analysis Fuels Map (see data and code availability). Wildfire perimeters from the National Burned Area Composite[82] (**b**) emphasizing the 2021, 2018, and 2017 wildfire seasons. The town of Lytton was largely destroyed in a 2021 wildfire.

Table 1 Statistics describing the vegetation, disturbance history, and anthropogenic factors of British Columbia and its regional zones.

	Central	Coastal	Northern	Province
Area (km^2)	440,949	205,476	326,848	973,273
Forested (%)[94]	80.8	69.6	73.6	76.1
Permanent nonfuel (%)[94]	9.7	21.7	11.1	12.8
Grassland/shrubland (%)[94]	8.5	8.2	13.5	10
Cropland (%)[94]	1.0	0.5	1.8	1.1
Average annual harvest (% of forested, 1980–2022)	0.43	0.20	0.05	0.27
Average area burned (% of vegetated, 1950–2021)	0.23	0.05	0.18	0.18
Average number of fires (≥20 ha, 1950–2021)	162.2	39.2	31.8	235.9
Median fire size (ha, of wildfires ≥10 ha, 1950–2021)	40.4	37	94	47.3
Proportion area burned by human-caused fires (%, 1950–2021)	27.9	37.6	39.5	33.2
Human-caused ignitions (%, 1950–2021)	60.2	73.2	60.6	61.6
Road density (km/100 km^2)	8.2	14.6	2.7	7.7
Area impacted by mountain pine beetle (% of forested area, 2001–2021)	53.7	1.9	20.0	33.2

Note that insect disturbance totals do not include areas subject to subsequent salvage logging. If not referenced, see data availability.

also comprise a non-negligible portion of grasslands (1%) and shrublands (7.2–12.5%); surprisingly, the proportion of agricultural lands is relatively low (<2%) (Table 1).

A land dominated by mountains, the physiography of BC has a strong influence on fire regimes. The Central zone comprises a series of mountain ranges, interspersed with valleys and plateaus. Historically, ecosystems in valleys in the rain shadow of the mountains and plateaus in the southern part of the zone had both surface (i.e., non-lethal to trees) (5–20 years intervals) and stand-replacing wildfires (150–250 years) as part of a mixed-severity wildfire regime. Stand-renewing wildfires were historically frequent (125–175 years) in forests on the central plateaus and infrequent to rare (250–300 years) on the windward western side of the interior ranges and at high elevation[13,14]. It has been the most fire-active zone in BC (followed closely by the Northern zone) over the last century and recorded a long history of Indigenous fire use, some areas having low mean fire intervals (e.g., 5–10 years)[15,16]. The Coastal zone, falling to the west but including the rugged Coast Range, hosts some highly productive, conifer-dominated forests, including its iconic old-growth forests. Much of the Coastal zone had infrequent stand-replacing fires (150–350 years) historically, with a mix of surface (50–100 years) and stand-replacing (100–300 years) wildfires in forests in the rain shadow of the Vancouver Island Ranges, and rare stand-replacing fires in high-elevation coastal forests (350–450 years)[13,14]. While naturally occurring wildfires are uncommon relative to the other two zones, evidence of fire is present throughout the zone and the millennia-long use of cultural burning has shaped ecosystems locally[17–19]. The Northern zone, with contrasting mountainous and relatively flat landscapes in the west and east, respectively, is composed of boreal and sub-boreal ecosystems. Wildfire regimes in this zone are typical for cold forests; that is, characterized by large, high-intensity (i.e., mostly stand-replacing) wildfires. Historically, stand-replacing fires were frequent (50–150) to infrequent (200–350) in the plains and mountains, respectively[13,14]. Ample prescribed and Indigenous burning occurs to this day, notably to improve elk, sheep, and bison habitat[20].

Although natural and anthropogenic factors have modified natural systems in BC for millennia, many fear that the current rate of anthropogenic change will compromise the resilience of natural and human systems[21]. Wildfire represents a strong transformative agent with immense implications for community vulnerability, ecosystem services, and carbon sequestration in BC. In this study, we examine the contemporary trends in wildfire activity in BC and discuss how a century of rapid climatic, demographic, and land-cover change may have contributed to the changing wildfire regimes. We ask: has climate change pushed BC, quickly and suddenly—if not unexpectedly—into a new fire epoch? Specifically, we compare the trends in fire activity over the past century across BC to annual climate variables known to influence fire activity. These trends are considered in the context of future projections of climate. We also discuss how the interplay between climatic and bottom-up (i.e., non-climatic biophysical or anthropogenic) factors, may have shaped contemporary fire regimes in BC. Finally, we discuss the ramifications of the current amplification in fire activity for the people and ecosystems of BC in light of the ongoing anthropogenic climate disruption.

Results and discussion

Top-down controls on BC wildfires: climate. Strong trends in temperature, precipitation, and an integrated measure of the two, the moisture deficit, have been observed in BC over the past century, and significant changes in the direction or breakpoints of these trends have been identified (Fig. 2). Although it is true that climate and fire activity fluctuates across decades to millennia, climates of BC have become more conducive to fire since ~2000 compared to previous decades, despite considerable year-to-year variability. Our results reproduce the previously reported wetting trend until ~2005[9], but show that the trend in moisture deficit has inverted to a drying one, in both spring (statistical breakpoint in 2011) and summer (breakpoint in 1999) (Fig. 2). In addition, the average length of the wildfire season inferred from weather records (the number of frost-free days) and the onset of fire activity (date at which 2% of the year's total area burned was reached) has increased by 26.7 and 27.1 days, respectively, since the early 20th century. Area burned correlates significantly to the climatic moisture deficit (CMD) (Fig. 3) and, accordingly, we observe a concomitant increase in area burned in BC (breakpoint in 2008) after a century-long decrease (Fig. 2). In short, even when total precipitation levels remain high, rapid warming results in increased evaporative demand. It was estimated that for every degree of warming, a minimum increase of 15% in precipitation is required to compensate for increased biomass flammability[22]. Our results show a precipitation increase of only 3.34% and 5.74% per degree of warming in spring and summer, respectively, for the period covering the modern rise in temperature (i.e., breakpoints).

A number of studies have pointed to the overriding role of temperature on the recent uptick in fire activity in western North America[23,24] and in other parts of the world[25]. However, all

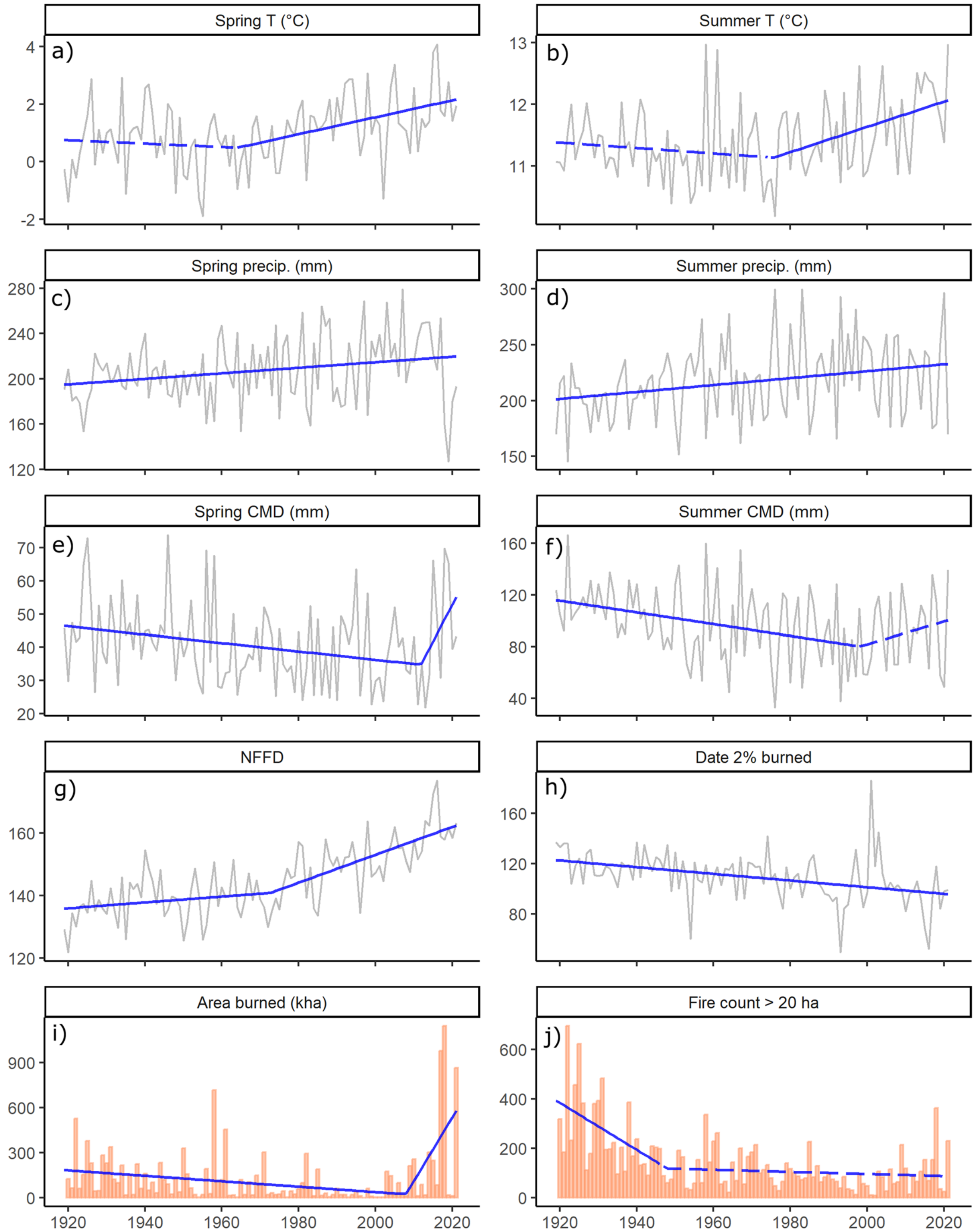

Fig. 2 Provincial trends in wildfire activity and climate of the spring and summer season, 1919-2021. Individual subplots show trends in temperature (**a**, **b**), total precipitation (**c**, **d**), climatic moisture deficit (CMD) (**e**, **f**), number of frost-free days (NFFD) (**g**), date at which 2% of cumulative annual area burned is reached (**h**), annual area burned (**i**), and annual number of fires larger than 20 ha (**j**). Gray lines indicate annual means and blue lines represent segmented regression trendlines. Solid lines indicate a significant trend (one-sided Mann-Kendall test, $p < 0.10$).

aspects of weather, including precipitation, relative humidity, and wind, influence fuel moisture, hence flammability, through their interactions with the relief and vegetation. The outcome of these complex interactions is evidenced in the highly variable fire environments in our study. Over the last century, the Central zone saw an increase in temperature (ΔTemp., 1970–2021 = 0.98 °C), an abrupt decline in summer precipitation, and an increase in summer CMD (Supplementary Fig. 2). This zone was also most affected by the recent mountain pine beetle epidemic (below), and experiences frequent synchronous wildfire ignitions, allowing the effects of reduced fuel moisture to translate into increased wildfire activity[26]. Interestingly, the CMD of the Central zone (and of BC) was higher at the beginning of the 20th century, suggesting a drier climate than that of the last decades, though it should be noted that there were few weather stations in inland BC in the early 1900s. Although the Coastal zone experienced the largest increase in temperature (ΔTemp. = 1.25 °C) and increases in spring and summer CMD, it did not see an increase in fire activity

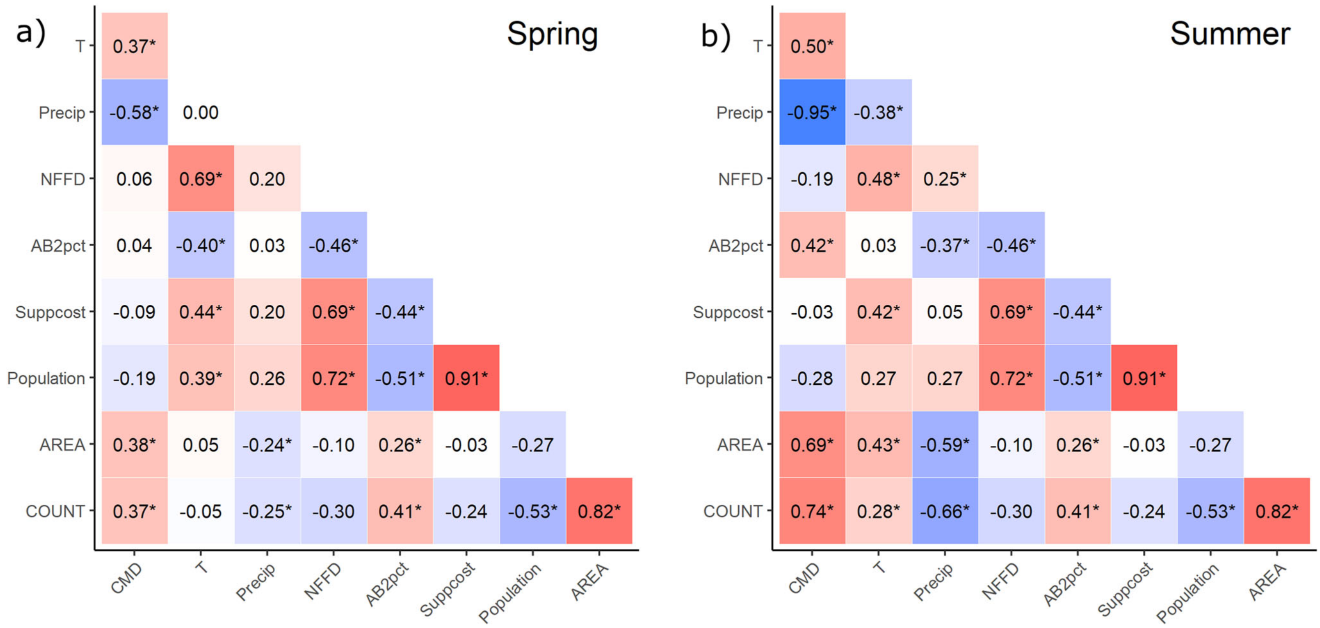

Fig. 3 Spearman correlations between wildfire activity and environmental variables by season. Spring (**a**) and summer (**b**) variables include climatic moisture deficit (CMD), average temperature (T), precipitation (Precip), number of frost-free days (NFFD), the date at which 2% of cumulative annual area burned is reached (AB2pct), annual suppression cost (Suppcost), area burned (AREA), and number of fires over 20 ha (COUNT). Significance ($p < 0.05$) of correlations is indicated by *.

(Supplementary Fig. 3). Despite the rapidly growing potential for wildfire, contemporary wildfire occurrence is low compared to the first half of the 20th century, a period of heavy industrialization due to extensive logging, land clearing, and mining on the coast (as in the Central zone). The Coastal zone is inherently less flammable than the Central and Northern zones, in part due to ignition limitation (lightning storms are rare) and the tall forests less prone to crown fire. Historically, large fires in coastal forests were often linked to offshore outflow events bringing warm dry air and high winds from the interior, as it occurred in the state of Oregon, USA, the 1933 Great Tillamook Fire[27] and more recently during the 2020 wildfire season[28]. The increasing summer CMD in the Coastal zone suggests a need for heightened alertness for these "fire winds". The temperature increase in the Northern zone was the lowest of the three zones (ΔTemp. = 0.61 °C), with concomitant increasing trend in summer wetness and lower CMD (Supplementary Fig. 4). While a rapid increase in wildfire activity in this zone may not appear imminent, in 2023 the area experienced its most active wildfire season—by far—of the last century, with nearly 1 Mha burned by August 24, compared to the previous annual maximum of approx. 0.4 Mha.

Wildfire ignition and spread is determined primarily by day-to-day weather superimposed on (and also affected by) broad climatic patterns and oscillations including El Niño–Southern Oscillation/Pacific Decadal Oscillation[29,30], making fingerprinting the specific effects of climate change on fire activity challenging. With all else being equal, a climate characterized by more hot, dry, and windy days will invariably lead to more ignitions, faster spreading, longer-burning and, ultimately, larger wildfires[31]. In recent years, the extreme fire-conducive weather in BC led to numerous large wildfires that burned for weeks to months, but are those conditions the outcome of a changing climate? A formal attribution study shows that the fire activity of the 2017 wildfire season can confidently be associated with the recent climate disruption[32]. Unsurprisingly, the massive 2021 heat dome that yielded record temperatures is an almost-certain outcome of human-induced climate change: it is one of the most extreme weather events ever recorded in BC[33] and is estimated to have been 150 times less likely to have occurred without the changing climate[34]. In the western US, Abatzoglou and Williams[35] have convincingly demonstrated that the sharp increase in fire activity is mostly the result of prolonged annual moisture deficits. Coherent with these results, we report significant correlations between fire-activity metrics (area burned and fires ≥20 ha) and several climate variables in BC, from 1919 to 2021 (Fig. 3). Given the current and projected climate trajectory, it is likely that the potential for wildfire will continue to increase in the upcoming century, even under the most optimistic climate scenario[11]. According to CMIP6 projections, the brackets of temperature increases are highly coherent among zones, whereas CMD values may vary considerably, from the highest deficit in the Central zone to the lowest in the Northern zone (Fig. 4).

A recent global analysis depicting the fire weather trends of the last few decades shows that the southern half of BC has experienced a significant increase in extremes of fire-conducive weather, as part of a continuous pattern that is prevalent in much of the western USA[24]. Unlike US states to the south, however, the increasing trend in area burned in BC occurred later (2008 breakpoint) than northwestern states (mid-1980s), the Interior West and Southwest (mid-1980s)[36], or California (early 20th century) (Supplementary Fig. 5). Although the trends in temperature are similar among areas, it is difficult to compare moisture deficits, as the range of values differs greatly among areas; California, for instance, has an average CMD that is about five times greater (i.e., drier) than BC (Supplementary Fig. 5). Beyond the changes in the intensity of climate warming and drying, one may wonder if changes in large-scale weather patterns may be influencing fire weather in BC. The possibility of dynamical changes to the jet stream due to rapid arctic warming and an associated increase in midlatitude extreme weather patterns has been suggested[37], but this connection is not yet well understood[38]. Regardless, even prior to the 2021 heat dome, background warming of the climate was likely increasing both the

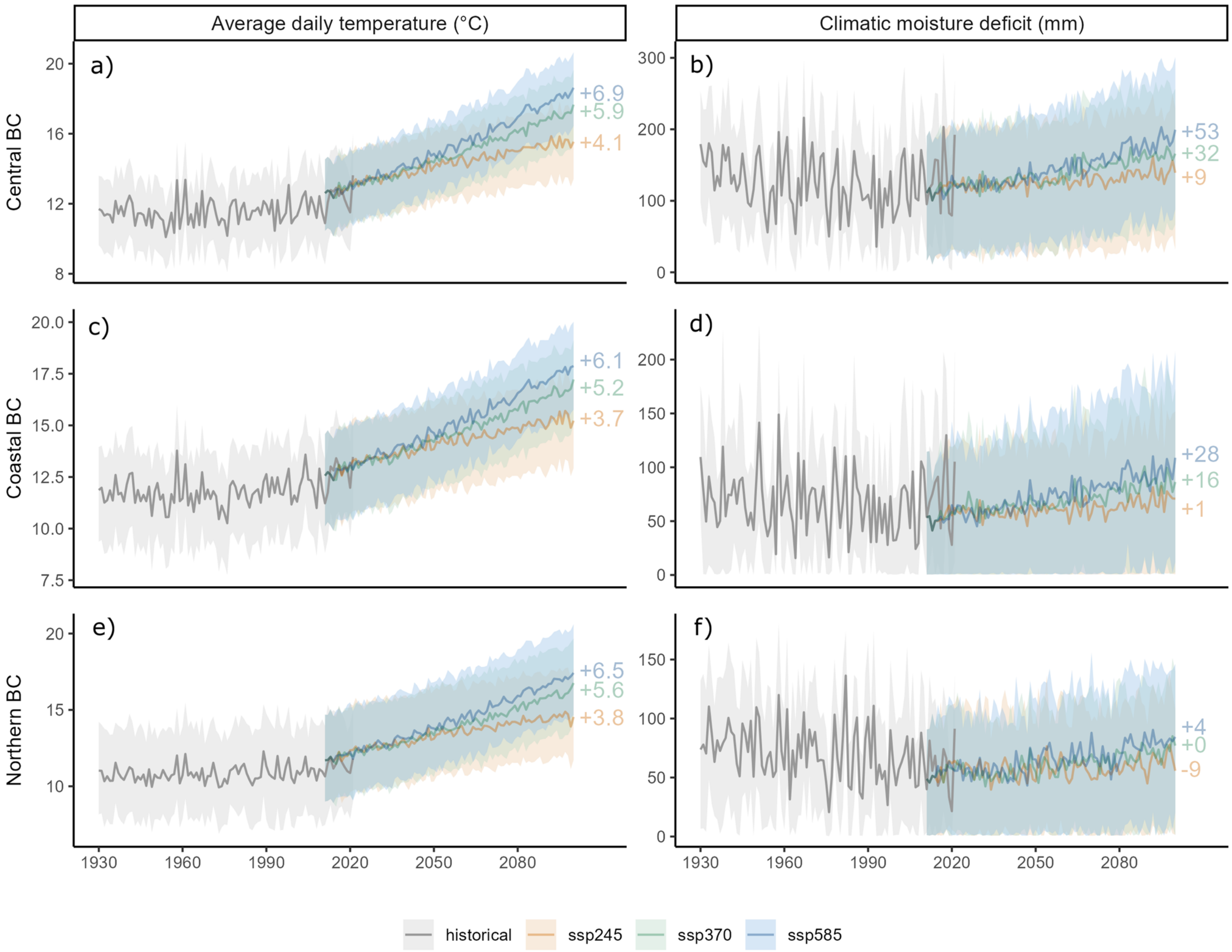

Fig. 4 Provincial trends in average daily temperature and climatic moisture deficit (CMD) for the summer months from 1930 to 2100, by zone. Projections shown are three CMIP6 Shared Socio-economic Pathway (SSP) scenarios (ssp245, ssp370, spp585)[78], averaged over the Central zone (**a**, **b**), the Coastal zone (**c**, **d**), and the Northern zone (**e**, **f**). Shaded region represents standard deviation of records across the zone of interest.

size and intensity of heat waves that may be linked to wildfire episodes[39,40]. When numerous fire ignitions occur during sustained and large-scale weather events, they will yield a large number of out-of-control synchronous wildfires that rapidly overwhelm fire-suppression capabilities[41]. This syndrome perfectly describes the 2017, 2018, 2021—and now, 2023—wildfire seasons in BC. While widespread, synchronous wildfire events have occurred for centuries or more (e.g.,[42]), projections of future ignition rates suggest that they will become more frequent and further undermine fire-protection efforts[43].

Bottom-up controls: fuels, land-use history, and fire-management policy. Whereas wildfires across the province of BC are largely governed by climate and weather, bottom-up factors further influence fire activity at the local scale. This is particularly evident with respect to fuels, for which the legacy and cumulative impacts of past wildfires, insect outbreaks, and land-use practices (e.g., logging, agriculture, grazing, urban development) have influenced—and continue to do so—the current fire regimes of BC[44]. In addition, substantial evidence of cultural burning in coastal, interior rainforest, and sub-boreal ecosystems across BC bear the imprint of past and current Indigenous fire stewardship. Fires in coastal temperate rainforests have been chiefly human driven, and the effects of fire exclusion were more pronounced in places where human ignitions comprised the majority of fire starts prior to European contact[19]. An illustration of bottom-up impacts is shown in an area of central BC, with a focus around the 2021 Sparks Lake Fire, near the city of Kamloops (Fig. 5). Although it is beyond the scope of this study to provide a synthesis of the effects of disturbances on wildfire occurrence, this map illustrates the magnitude and extent of landscape changes that have occurred in the decades prior to the 2021 wildfire season. Along with more accurate climate projections, gaining a better understanding of how natural and anthropogenic disturbances affect subsequent fire ignition and growth on BC landscapes is critical to improving forecasts of future wildfire activity, either for the next season or over the next few decades. This is a formidable task, however, given the diversity of BC's vegetation types and their complex interactions with climate and disturbance regimes[45,46].

The extent of the most recent mountain pine beetle (*Dendroctonus ponderosae*) outbreak caused extensive mortality over ~15 Mha of forest in BC in the late 1990s and 2000s throughout most of the Central zone and in parts of the Coastal and Northern zones (Table 1). The outbreak was aggravated by decades of aggressive fire suppression leading to a shift in age distribution to older, susceptible pine stands, in conjunction with

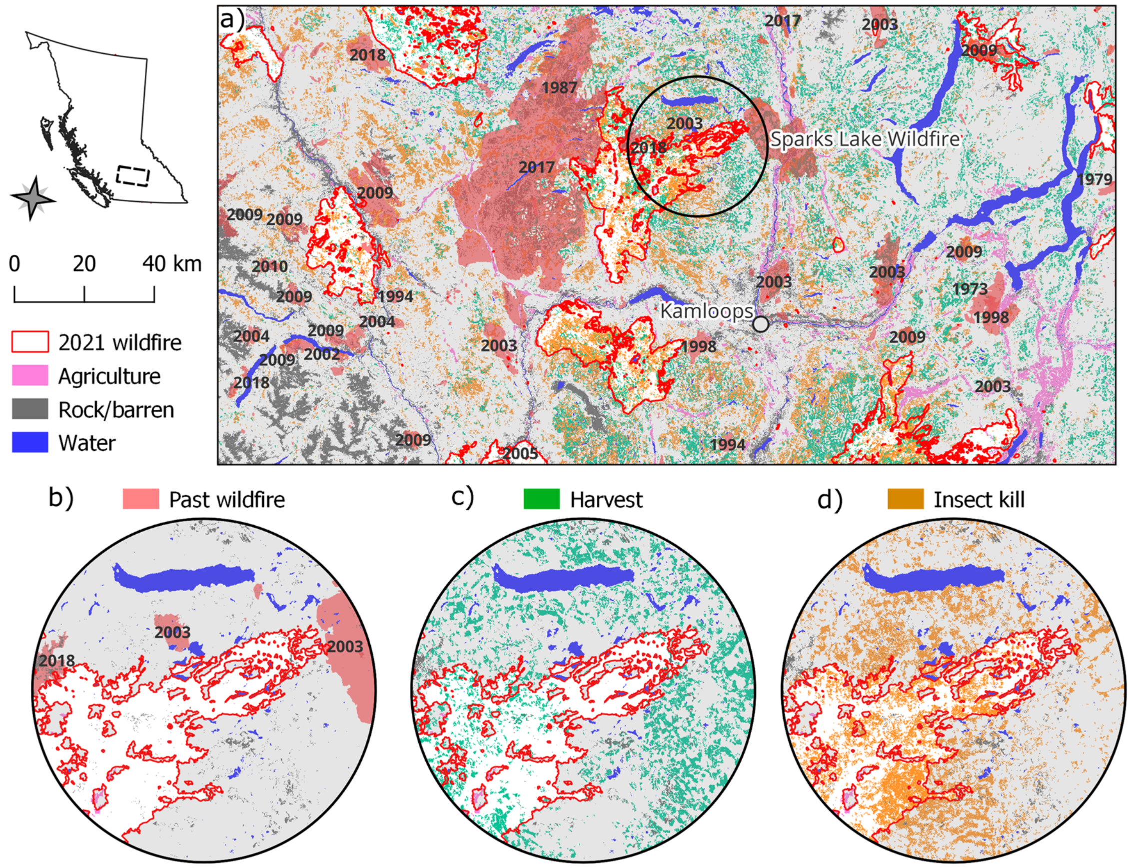

Fig. 5 Landscape disturbance history in the vicinity of the 2021 Sparks Lake Fire (86,827 hectares) near Kamloops, BC. Regional context (**a**) and local context depicting areas that were burned by historic wildfires (1971–2020) (**b**), harvested for forestry purposes (1984–2015) (**c**)[92], or affected by mountain pine beetle (*Dendroctonus ponderosae*) (1984–2015) (**d**)[92].

warming winters[47,48]. The specific influence of beetle-affected stands on fire occurrence and behavior, while debated elsewhere[49], are clear in hard-hit areas of BC: fire spread rates are higher in recently attacked stands[50], whereas severe deadfall later on has challenged fire-management activities[51,52]. Although the precise impact of beetle attack is unknown, analysis from the US Pacific Northwest found a 1.61-fold increase in fire likelihood following beetle attack, compared to unaffected stands[53]. More ambiguous are the interactions between forest harvesting and wildfire. BC has a vigorous forest industry (193,000 ha/years harvested, on average, since 1990; https://www.for.gov.bc.ca/) with a long (~150 years) history of commercial harvesting in some regions. Forestry practices (e.g., harvesting, salvage logging, replanting, etc.), as well as their effects on wildfire occurrence, vary considerably among regions and forest types. Many areas have been heavily logged and replanted, to a point where management has altered the potential for wildfire occurrence, either negatively, through removing flammable biomass[10] and reducing connectivity between flammable stands or positively by artificially increasing the proportion of forest cover or altering post-harvest species compositions to favor more flammable tree species. For example, forest cover has increased at the expense of grassland and shrublands in some dry forests in southeast BC since the 1950s, a trend that contributes to the current potential for crown fires[54]. Similarly, logging has contributed to structural stand changes that favor wildfire ignition and spread in coastal forest types ill-adapted to intense fire[8,17].

The long-term impact of fire suppression on wildfire potential in North America is increasingly being recognized[6,55]. With a fire-management policy that can be described as “hit it hard, hit it fast” over most of its landmass, it seems plausible that decades of successful fire exclusion, combined with the suppression of Indigenous cultural burning practices[56], have led to a fire deficit in some areas[57]. These policies have contributed to a densification of forest stands relative to the pre-suppression era in parts of BC and, by extension, increased the likelihood of large, high-intensity wildfires[15,17]. Deficits are often concentrated around human values we are trying to protect (i.e., communities, parks and protected areas), creating the unintended consequence of increasing fire likelihood[58] and potentially causing profound ecological change. This is the case for many grassland ecosystems and woodlands across BC that were historically maintained through complex Indigenous fire management systems involving frequent cultural fires and lightning-ignited fires. These interactive and generally low-severity fire regimes have been disrupted through decades of fire suppression and human land-use change[17]. Direct fire-suppression costs are continually increasing in tandem with burn rates and a rapidly expanding wildland-urban interface[59] (Supplementary Fig. 6). At the same time, the scale of post-harvest fuel mitigation work has decreased significantly over the past three decades. Prior to the early 1990s, prescribed burning (specifically, broadcast burning, as well as burning for wildlife habitat) occurred across tens of thousands of ha/year[3]. By the early 1990s the use of prescribed fire had decreased to less than 10,000 ha/year[3].

While the direct effects of weather on wildfire ignition and spread are increasingly well understood, the indirect effects of climate change on future wildfire activity shroud our forecasts with massive uncertainty. In south-central BC, it has been suggested that the hot and dry weather that drives large wildfires may also lead to a depletion of flammable biomass[60]. Rapid compositional and structural changes to some forest types due to accelerated tree mortality (i.e., through drought, insect outbreaks, or pathogens) may lead to unanticipated and unpredictable effects on wildfire occurrence and fire behavior[30,61]. Even though the paleo-record points to dramatic shifts in fire activity and resulting vegetation in BC over the last few millennia[62], the current situation is firmly without analog in either the biophysical context or anthropogenic setting, but also due to the rapidity of climatic changes. To counter this uncertainty, a growing interest in climate-smart landscape and land-management strategies for BC show promise in augmenting our ability to adapt to a rapidly changing disturbance regime[63]. One such adaptation strategy consists of manipulating forests to reduce their vulnerability to severe wildfires, bark beetle attacks, and climate change by coupling trees having specific traits with that of novel environments and fire regimes[64,65].

Looking ahead. With four wildfire blowup seasons (2017, 2018, 2021, and 2023) in 7 years—and associated destruction, threats, and hardship to human and ecological communities—BC now appears to have arrived at its place as a hotspot for catastrophic wildfire losses, along with Australia, the western US, and the Mediterranean Basin. As BC shares some of the ecosystems and weather systems that drive many fire regimes of the western US, it is similarly and unequivocally on that same trajectory of fire-regime change, albeit with a delay relative to the inflexion point documented in some coastal states of the western US[36,66] (Supplementary Fig. 5). Just as British Columbians became accustomed to the relatively low burn rates of the late 20th century, they are now confronted with a harsh reality of more frequent years of intense and prolonged wildfire activity. Moreover, there is no indication that an upward trend in climate-induced wildfire potential will stabilize in the near future, as even the coolest and wettest climate projections point to an increase in moisture deficit until at least the end of the 21st century in many parts of the province[67,68] (Fig. 4). From a global perspective, the surge in wildfire activity observed in BC is disquieting, especially if it heralds—as projected—similar increases in the neighboring vast, carbon-rich boreal biome[69]. Despite a rapid rise in temperature observed in the adjacent Northwest Territories and Yukon over the last half-century, no significant increases in area burned or moisture deficit have been observed in recent decades (Supplementary Fig. 5).

Looking into the past suggests that, while the nature of a modern fire environment may be unique, high annual rates of burning are not unprecedented. Several years prior to the recent string of severe wildfire years in California, Stephens et al.[70] concluded that "[…] prehistorically a large amount of California burned every year". In fact, their multi-proxy reconstruction suggests that the burn rates from 1950–1999 constituted a mere 5.6% of the European pre-settlement rates, a decrease mainly resulting from the exclusion of Indigenous cultural burning practices and widespread land-cover change (mainly agricultural and urban). Since the publication of that article, the state, as well as much of the western US, has endured the dramatic climate-induced increase in fire activity that is further exacerbated by a lengthening of the wildfire season caused by the numerous human-caused fires throughout the warm months[71]. BC may be in a similar historic fire-deficit situation, as reported by Smith[72], who suggests a possible ten-fold decrease in contemporary burn rates compared to those of the European pre-settlement period. While it is difficult to interpret the relevance of these historical burn rates in today's reality, it underscores the often-underestimated burning potential of fire-prone landscapes and opens the door to further discussions on how to better coexist with fire[73].

The recent amplification in the fire regimes of BC, in conjunction with its ever-expanding wildland-urban interface, bear many consequences for British Columbians. The steady rise in community evacuation orders and evacuees come with a heavy human and economic cost (Supplementary Fig. 7). The population of BC has mourned the loss of civilians and fire fighters, experienced significant destruction of homes and forest values, endured enormous disruption caused by evacuations, and suffered exposure to harmful chemicals from smoke. Yet, we are only beginning to understand the effects of wildfires on people's mental and physical health[74–76]. Cascading secondary effects of wildfires, such as debris flow, flooding, and mudslides can also be devastating, as shown in the years following the 2003 wildfires in south-central BC[77]. Destructive floods covered much of central BC a few months after the 2021 wildfires, but it is still unclear how much of a role wildfires may have played in such a large-scale event[78]. In July 2022, a wildfire two kilometers west of Lytton destroyed several houses almost a year after burning down the town, serving as a clear reminder that as long as there is flammable vegetation and hot, dry, windy weather, a wildfire may ignite and spread.

Though daunting, the current conjuncture in BC provides a strong impetus for accelerating efforts towards fire adaptation and mitigation that protect human communities and maintain essential ecosystem services within a broader climate change adaptation context[79]. To take on this task, many tools are available: landscape fire management plans enabling prescribed burning, Indigenous-led cultural burning, fuel mitigation treatments, optimization of forest harvesting, and species conversions, as well as revised urban planning and building codes and practices, and enhancing preparedness and resilience in fire and emergency organizations. Mitigation strategies such as fuel treatments must, however, be tailored to the diverse vegetation types and wildfire regimes of BC; for instance, prescribed burning and tree thinning may be appropriate for dry forests, but other strategies should be considered for moist coastal areas (e.g., retention and promotion of old-growth features) or boreal forests (e.g., harvesting, broadleaf-species conversion)[80,81]. It is becoming evident that we require place-based efforts across firescapes that are both creative and sustained to confront the magnitude of the wildfire challenge in different socioeconomic and ecological situations across BC. This may involve a philosophical change in the way we think about wildfires to an outlook accepting more wildland fire where it makes sense (i.e., for protection or ecological purposes) while emphasizing people's role in proactively managing fire-prone landscapes[82]. Our ability to respond to rapid and unsettling changes in our fire environment must overcome our cognitive dissonance or normalcy biases. To counter this, a critical step in adapting to fire is to recognize and accept that BC has entered a new and uncertain fire epoch.

Methods

Climate and fire data. We summarize historical and projected climate data from 1900 to 2100 for BC and three nested zones (Fig. 1), as well as five selected US states and Canadian provinces. These climate data are interpolated using ClimateNA v7.31[83] at a 50-km resolution, including three WorldClim CMIP6 Shared Socio-economic Pathway (SSP) scenarios (ssp245, ssp370, spp585) from 2021 to 2100[84]. To limit collinearity, we selected a set of variables having $|r| < 0.7$ (Spearman correlation): seasonal mean temperature, total precipitation, and Hargreaves CMD for spring (March, April, May) and summer (June, July, August), and the annual number of frost-free days. We measured the association among variables using a Spearman correlation test modified for serially correlated data[85] (Fig. 2) implemented in the *astrochron* R package[86].

Mapped wildfire perimeters were drawn from the Canadian National Fire Database for 1919–1984[87] and the National Burned Area Composite[88] for 1985–2021. We adjust fire polygon burned area estimates to compensate for missing unburned islands and perimeter inaccuracies arising from less-accurate sources such as manual delineation or GPS perimeters[89]. We excluded small fires (<20 ha) from this dataset, which were not consistently reported over the study period. We calculated total area burned per year, number of fires per year, and day-of-year at which cumulative area burned reaches 1%, 2%, 5%, and 10% of the annual total (the 2% threshold was retained).

Fire statistics for areas outside BC were summarized using the Canadian National Fire Database[87] fire occurrence data for Yukon and the Northwest Territories, the Fire and Resource Assessment Program historical polygons for California, and the Monitoring Trends in Burn Severity fire polygons for Washington and Oregon[90].

Fire suppression costs and evacuations. Direct fire suppression costs were compiled from BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development Annual Reports[91] for 1919–1969, Stocks and Martell[92] for 1970–2009, and BC Wildfire Service Annual Reports[93] for 2010–2021. All costs were adjusted for inflation based on the historical consumer price index[94]. Data on evacuations were drawn from the Canadian Wildland Fire Evacuation Database (see data availability).

Trend analysis. All climate and fire variables were plotted as a time series for 1919–2021. We used the "segmented" function from the *segmented* R package[95] to estimate segmented linear relationships for all variables across the study period (Fig. 3). This uses maximum likelihood estimation to test whether piecewise linear regression of two (or more) parts better fits the data than normal linear regression, and estimates breakpoints and slopes for each component part of the segmented regression. We tested the statistical significance of segmented trends using a modified Mann-Kendall trend test, with a variance correction for serially correlated data[96], available from the *modifiedmk* R package[97].

Forest disturbance maps and statistics. Harvested cutblocks and areas affected by the mountain pine beetle (*Dendroctonus ponderosae*) epidemic of the 1990s and early 2000s were obtained from the CanLAD dataset[98], which is a 30-m resolution satellite-derived dataset of land cover change for the period of 1986–2020. The fire history of the area, from 1919 to 2021 was mapped from the previously mentioned fire polygon datasets, and cropland was mapped using the 30-m resolution 2010 Canada Land Cover dataset[99].

We summarize spatial statistics of forest disturbance and land cover by provincial and ecozone averages (Table 1). Land cover statistics are summarized from SCANFi land cover dataset, a version of the CanLAD dataset family[100].

Data availability

The datasets generated during this study are available at the Centre for Open Science OSF data repository [https://doi.org/10.17605/OSF.IO/2G3QK][101]. All climate data was accessed and interpolated using ClimateNA v7.31, available at https://climatena.ca/. Fire perimeters and point data for Canada were downloaded from the Canadian Wildland Fire Information System Datamart at https://cwfis.cfs.nrcan.gc.ca/datamart. Fire polygon data for California were downloaded from the Fire and Resource Assessment Project at https://www.fire.ca.gov/what-we-do/fire-resource-assessment-program. Fire polygon data for Oregon and Washington were downloaded from the Monitoring Trends in Burn Severity Project at https://www.mtbs.gov/. Although the Canadian Wildland Fire Evacuation Database is not publically-accessible, BC-specific data summarized from this database are included in the OSF data repository. tPublic road shapefiles, used for regional statistics, are available from the CanVec dataset https://open.canada.ca/data/en/dataset/2dac78ba-8543-48a6-8f07-faeef56f9895. BC cutblock shapefiles, used for regional statistics, are available from https://catalog.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-. Vegetation cover maps for Study Area figure accessed at https://cwfis.cfs.nrcan.gc.ca/downloads/fuels/development/. Mountain Pine Beetle impact extent was calculated from polygons available at the BC Government Ministry of Forests data portal, https://www.for.gov.bc.ca/ftp/HFP/external/!publish/Aerial_Overview/.

Code availability

All analysis was conducted in R version 4.2.2. Specialized R packages used in the analysis include astrochron[86], segmented[95], and modifiedmk[97]. Code and data for replicating the analysis are archived at the Centre for Open Science OSF data repository [https://doi.org/10.17605/OSF.IO/2G3QK][101].

Received: 15 November 2022; Accepted: 25 August 2023;
Published online: 05 September 2023

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Acknowledgements

We thank Andreas Hamann for his assistance with preliminary model inputs and interpretation of mid-century climate trends. M.-A.P., Q.E.B., P.J., S.G.T. and E.W. acknowledge funding from Natural Resources Canada as part of the work towards the Emergency Management Strategy for Canada.

Author contributions

M.-A.P., Q.E.B., P.J. and E.W. designed the paper with help from M.L.B, L.D., M.D.F., R.G., K.M.H., S.L.S. and S.W.T.; Q.E.B. analyzed data with input from M.-A.P., Q.E.B., P.J. and E.W. and M.-A.P. led the writing in collaboration with Q.E.B., P.J. and E.W. All authors read and edited this manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43247-023-00977-1.

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Peer review information *Communications Earth & Environment* thanks the anonymous reviewers for their contribution to the peer review of this work. Primary Handling Editor: Yongqiang Liu and Aliénor Lavergne.

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