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Wildfire adaptation in the Russian Arctic: A systematic policy review

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ABSTRACT

A scientific consensus acknowledges that climate change has increased wildfire activity in the Russian Arctic, a trend projected to continue in response to further warming. Regional governments across Russia have started to design and develop adaptation policies and plans (i.e. outputs) to this end. Our comprehensive understanding on the state of wildfire adaptation in policy is limited. In this article we systematically review policies and plans developed to adapt to wildfires in the Russian Arctic. Using systematic approaches, we identify 12 wildfire adaptation outputs adopted between 2008 and 2020. Our findings indicate that wildfire adaptation outputs are aimed at reducing the risk of wildfires and improve wildland fire response, implemented through legislative and regulatory mechanisms, developed at the regional level, adopted in response to national mandates, and mainstreamed into existing forest management policies. Although there is evidence of wildfire adaptation planning occurring in the Russian Arctic, we find that the nature and extent of wildfire adaptation outputs are not sufficient to address the seriousness and severity of climate change, with key shortcomings found in relation to the scientific, human, and management characteristics. We argue that expanding the profile of climate change research in the Russian Arctic and improving the dialogue among researchers, local and Indigenous peoples, and decision-makers are critical for providing useful recommendations for policy makers to accelerate wildfire adaptation in the Russian Arctic.

1. Introduction

There is an emerging consensus that climate change has increased wildfire activity across the Arctic region (IPCC, 2019; Ciavarella et al., 2020). Area burned as well as fire frequency and severity are higher now than in the last 10,000 years (IPCC, 2019), and further

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increases are projected as a result of climate-driven changes in fire danger conditions (de Groot et al., 2013; Kelly et al., 2013; Akenteva et al., 2017; Seidl et al., 2017; Torzhkov et al., 2019; Son et al., 2021). In the Russian Arctic, wildfires are becoming a particular problem, with recent years witnessing intense fire activity (Leskinen et al., 2020; York et al., 2020; Kirillina et al., 2020). The number of fire events in the Siberian region of Krasnoyarsk Krai, for instance, increased from 733 in 2007 to 2,400 by 2019, and the total area affected by fires from less than 0,03 Mha to 2,000 Mha over the same period (Government of Krasnoyarsk, 2020). This increased fire activity portends significant repercussions for ecosystems and humans. Of particular concern are the health effects associated with contaminated water systems (Robinne et al., 2018) and smoke pollution (Liu et al., 2015), which are expected to increase the risk of a range of respiratory, cardiovascular, and psychiatric problems (Reid et al., 2016; Kizer, 2020; Zhang et al., 2020), also interacting with the COVID-19 pandemic (Ford et al., 2022). Increased wildfire activity is also projected to increase the damage to critical infrastructure and services; challenge the preparedness and effectiveness of fire management and planning; alter ecologically important fire-vegetation interactions; and disrupt livelihoods activities due to the loss of important ecosystem services and habitats (Akenteva et al., 2017; Brecka et al., 2018; IUFRO, 2018; Coogan et al., 2019; World Bank Group, 2020; Durova, 2020). New opportunities associated with biodiversity conservation and economic productivity are also expected to arise (Musetta-Lambert et al., 2017; Torzhkov et al., 2019). To manage these impacts and take advantage of new ones, it is important to incorporate climate change adaptation policies and measures into fire management and planning in the Russian Arctic.

Some regional governments across Russia have already addressed increased wildfire activity. In 2013, for instance, the St. Petersburg's Climate Adaptation Strategy identified forest fires as a concern for the future development of the city (Government of Saint Petersburg, 2013). In the Ural District, the Khanty-Mansi Autonomous Okrug recently set out a roadmap to adapt to increasing wildfire activity through 2030 (Government of the Khanty-Mansi Okrug, 2018), and the Government of the Moscow Region approved a set of regulatory mechanisms to reduce the risk of future forest and peatland fires. In the Arctic region, wildfires were identified as a potential threat in the 'Adaptation strategy to the impacts of climate change on public health in the Arkhangelsk Region and the Nenets Autonomous Okrug' (Sidorov et al., 2012), highlighting how wildfires are becoming more dangerous and how they will have significant repercussions to human health and well-being.

At the national level, the Government of the Russian Federation requested through the Climate Doctrine (2009) that interested ministries and departments include long-term measures to adapt to wildfires in the development and implementation of their planning documents. The most recent National Adaptation Plan (2019) identified increased fire hazard in forest as a projected negative impact of climate change (Government of the Russian Federation, 2009; 2019).

Despite evidence of adaptation outputs in the form of policies and plans, synthesized knowledge on the state of wildfire adaptation policy and planning has been limited in the Russian Arctic. The first attempts to systematically assess the state of knowledge of adaptation across the Arctic demonstrated that limited adaptation efforts occur in Russia, finding no evidence of adaptation policies and plans specifically developed to adapt to wildfires over a 15-year period (2004–2020) (Canosa et al., 2020; Ford et al., 2014, 2015). While these reviews have helped to deepen our knowledge about adaptation in the Arctic, they focused on reviewing adaptations reported exclusively in the English-language peer-reviewed literature and may have thus omitted wildfire adaptation policies and plans reported in the 'grey literature' (e.g., government reports, websites, national assessments, etc.) and much Russian language research. Evidence of such limitation is found when examining recent assessment reports (AMAP, 2017; Leskinen et al., 2020) as well as a number of adaptation-focused studies in Russian (Lipka et al., 2020; Semenov et al., 2019), in which examples of wildfire adaptation policies and plans are discussed. It remains unclear, however, if these efforts represent a comprehensive profile of what is and is not being done on wildfire adaptation policy and planning in the Russian Arctic, with the majority focusing on Russia at a more general level and with only the Arctic Monitoring and Assessment Programme (AMAP, 2017) report documenting wildfire adaptation policies and plans from the Barents region. Similarly, the criteria by which these policies and plans were selected were not provided, limiting our ability to perform consistent, comparable, and comprehensive examination (Ford and Berrang-Ford, 2016). This constrains our ability to effectively characterize the current status of adaptation policy and planning in Russia and in the Arctic more generally; to assess the types and adequacy of wildfire adaptation policies and plans taking place; to inform future research directions and investments in climate change adaptation; to exchange insights from different regions facing related climatic stresses, and; to assess progress over time.

To address these problems, this study systematically reviews policy documents, strategies, initiatives, and programs (i.e. outputs) developed to adapt to wildfires in the Russian Arctic, combining three different data sources widely utilised in adaptation tracking studies (Araos et al., 2016; Lesnikowski et al., 2016; Biesbroek and Delaney, 2020). By using multiple sources, this review fills existing knowledge gaps and develops a comprehensive dataset of wildfire adaptation outputs while maintaining a consistent, coherent, comprehensive, and comparable approach for tracking adaptation (Ford and Berrang-Ford, 2016). The aims are: (i) to identify, characterize, and assess the state of knowledge on climate change adaptation outputs to wildfires in the Russia Arctic; (ii) to build up a more comprehensive profile of Arctic adaptation; and (iii) to inform a research agenda on human adaptation in the Russian Arctic and raise its profile within the climate change adaptation scholarship.

2. Wildfires in the Russian Arctic and the need for climate change adaptation

Wildfires are dominant ecological disturbance affecting ecosystems in the Russian Arctic (Shvidenko and Schepaschenko, 2013; Kharuk and Ponomarev, 2020; FAO, 2020; Leskinen et al., 2020). From 2000 to 2020, more than 70 % of all wildfires registered in Russia, and up to 90 % of the total area burned, were documented in the boreal forest belt of Siberia (between 55°-65° N), while 3 % of the total number of fires occurred in the tundra and forest-tundra zones over the same period (above 65°N) (Conard and Ponomarev, 2020; York et al., 2020; Kharuk et al., 2021). Many have argued that in high latitudes of Siberia the main source of fires (up to 90 % of cases) is lightning strikes in Larch (Larix sibirica) forests, especially during "dry thunderstorms" with minimal precipitation occurring at high temperatures and low relative humidity (Kharuk et al., 2021; Ivanov and Ivanova, 2010). Fires occurring in remote areas are not suppressed – they are left to burn naturally because of low population density, absence of effective detection and monitoring, and lack of a threat to settlements and economic facilities. Yet, approximately 70 % of all detected fires are extinguished within two days from detection in most regions that extend into the Russian Arctic, particularly below 65°N (Conard and Ponomarev, 2020). Wildfires in the Russian Arctic have considerably increased in recent years and are expected to further increase as a result of climate-induced changes, challenging socio-ecological relationships and the ability of fire management agencies to cope with increased wildfire activity, maintain important ecological processes, and protect human health and assets.

The Russian Arctic is experiencing some of the most dramatic climate change anywhere on the planet, with temperatures rising four times faster than the average global rate because of the polar-dependent amplifying effect (Akenteva et al., 2017; Edel'gereive et al., 2020). As a consequence, evapotranspiration is increasing, winter snowpacks are melting earlier, lighting activity is rising (Holzworth et al., 2020), and available surface and ground fuels are growing (McCarty et al, 2020), all of which is increasing the likelihood of a fire starting, its intensity and the speed at which it spreads. This is altering the structure and function of forest ecosystems by driving phenological changes (Davis et al., 2019); causing permafrost to thaw more rapidly (Gibson et al., 2018; Chevychelov, 2019); altering the hydrological controls over ecosystem processes (Li and Lawrence, 2017); and challenging the ecological resilience of the Arctic (Johnstone et al., 2016; Stevens-Rumann et al., 2018; Barber et al., 2018; Whitman et al., 2019). Wildfires are also affecting albedo as well as organic carbon stocks and sequestration capacities, which are significant factors in regulating global and regional climates (Walker et al., 2019; Liu et al., 2019). Thus, the effects of climate change on the physical and biological characteristics of wildfires are significant in the Russian Arctic, with future, long-term projections indicating further transformational changes by the end of the century.

Climate-induced changes on northern fire regimes are also expected to physically and economically challenge fire management and planning (prevention, detection, monitoring, suppression) in Russia, and Arctic-wide (Isaev, 2011; Balalaev, 2018; Shpakovsky, 2018; Tymstra et al., 2020). Model estimations found that the number of wildfires could double in Russia by the end of the century under changing climatic conditions, which in turn is expected to increase the number of days when fire intensity exceeds suppression capabilities (Flannigan et al., 2009; Podur and Wotton, 2010; Shvidenko and Schepaschenko, 2013; Melvin et al., 2017; Wotton et al., 2017). The costs of managing such increased wildfire activity will also rise in the future. Torzhkov et al. (2018) estimated that the cost of wildfire management in Russia could increase by 249 million rubles per year (∼3 million EUR) by the end of the century due to increased climate-induced wildfire activity. These findings are a cause for concern, given that Russian fire management agencies have reduced budgets to respond to wildfires and are already struggling to manage large and severe wildfires (Goldammer, 2013; Sokolov et al., 2013; Balalaev, 2018). Human-ignited fires, socioeconomic transitions, political conditions, and changes in forest fuel composition, structure and load due to decades of fire suppression also contribute to the challenge of managing wildfires in a changing climate.

At the same time, the effects of climate change on Russia's fire regime may lead to large economic and social damages and losses. Impacts include increased exposure to air pollution; contamination of water resources; diminished forest productivity and economic activity; and disrupted transportation routes and supply chains, with consequences well beyond the Arctic (Bondur et al., 2020; Rodriguez-Cardona et al., 2020). The impacts of wildfires are particularly pertinent for Indigenous groups in the Russian Arctic, many of whom directly depend on the tundra, forest-tundra, and boreal forests (AMAP, 2017; Lavrillier and Gabyshev, 2017). For example, recent studies documented that increased fire activity is affecting the health, abundance, and migration patterns of many mammal, fruit-bearing shrubs, and tree species throughout the Arctic region (Johnstone et al., 2016; Barber et al., 2018; Whitman et al., 2019; Kharuk et al., 2021). This, in turn, is impacting many rural and Indigenous communities whose livelihoods, community social networks, and lifestyles rely on traditional subsistence-based practices (Bogdanova et al., 2021). Indigenous communities in the Russian Arctic also have limited access to emergency services, inadequate wildfire protection infrastructure, and weak capacity and preparedness to fire risk disturbances, which may lead to premature deaths, critical health effects, and economic losses in light of projected increases in wildfire activity (Leskinen et al., 2020; Solovyeva and Kuklina, 2020).

Forest ecosystems in northern Russia are a basic pillar of the socio-economic development of the Russian Federation, providing valuable ecosystem services to local and Indigenous communities as well as to a significant proportion of the global population (e.g. food, raw materials) (FAO, 2020; Carr et al., 2021). Russian forests also perform important climate control functions at the local, regional, and global level, with great potential to alter the rate of climate change through fire-related greenhouse gas emissions and associated feedbacks (Prosperi et al., 2020). Failing to adapt to increased wildfire activity in a sustainable manner would therefore have major implications well beyond the Arctic, particularly by contaminating freshwater resources, increasing air pollution, and releasing greenhouse gases (Robinne et al., 2018; Rodriguez-Cardona et al., 2020). Such impacts would jeopardize the fulfilment of internationally recognized mitigation and adaptation climate targets and goals, including objectives delineated in the Paris Agreement's '1.5° Goal' (Article 2), 'Global Goal on Adaptation' (Article 7), and the UN Sustainable Development Goals (SDGs) (UNFCCC, 2015; United Nations, 2015). Thus, the burning of the Russian Arctic should be viewed as a global issue. It is in this context that the understanding of if and how authorities in Russia are addressing increased wildfire activity is urgently needed in order to ensure and support the development of accountability mechanisms and evaluation of adaptation outputs.

3. Methodology

For the purpose of this study, *adaptation outputs* were defined as policy instruments adopted by governments at different administrative levels that are intentionally designed to address current and/or projected impacts of climate change on northern wildfire regimes (Dupuis and Biesbroek, 2013). Hence, our review only includes policy instruments that were purposefully designed to respond to both the current and/or projected impacts of climate change. This means that policy instruments that reduce vulnerability and increase adaptive capacity but do not explicitly refer to adaptation were not included in this review, consistent with other adaptation tracking research (e.g. Lesnikowski et al., 2016; Biesbroek and Delaney, 2020). For example, actions taken to improve fire response or concerned with general climate processes or weather were not included if there was not an explicit mention of climate change. Other concepts closely associated but different to adaptation – e.g. resilience, disaster risk reduction, sustainability, etc. – were also excluded (Gallopín, 2006; Mercer, 2010). As long as there is an *explicit intentionality* in the design of the policy instrument to climate change adaptation, these are included in our review (Dupuis and Biesbroek, 2013). Furthermore, it should be noted that we do not follow any particular definition throughout this review; instead, we recognize the diversity and ambiguity of key terms (e.g. vulnerability, resilience) and thus understand them according to the general consensus to avoid the exclusion of different framings and discourses. Similarly, the terms "forest fire", "wildland fire", "wildfire", and "fire" are often used interchangeably. We use the term "wildfire" to refer to all human- and lightning-caused fire in the natural environment, including forests and peats. Detailed information methodology, metadata and search methods, is presented in the supplementary material.

3.1. Data collection

The data source was publicly available information in both English and Russian-language reported in peer-reviewed literature journal articles, submissions to the United Nations Framework Convention on Climate Change (UNFCCC), and documents and contents from official governmental websites published over a 12-year period (January 2008-December 2020). The beginning of this period is marked by the publication of the first assessment report on climate change issued by the Russian Government, which led to the establishment of the Climate Doctrine in 2009 and the emergence of climate change as focal point of policy regulations and programs in the Russian Federation. The review focuses on northern Russia, following the geographical boundaries used in the Russian Presidential Decree N° 296, May 2, 2014, Land Territories of the Arctic Zone of Russia encompassing Murmansk Oblast, Republic of Karelia, Arkhangelsk Oblast, Komi Republic, Nenets Autonomous Okrug, Yamalo-Nenets Autonomous Okrug, Krasnoyarsk Krai, Republic of Sakha, and Chukotka Autonomous Okrug (Fig. 1). We limit our review to documents of national and regional (i.e. oblast, okrug, krai,

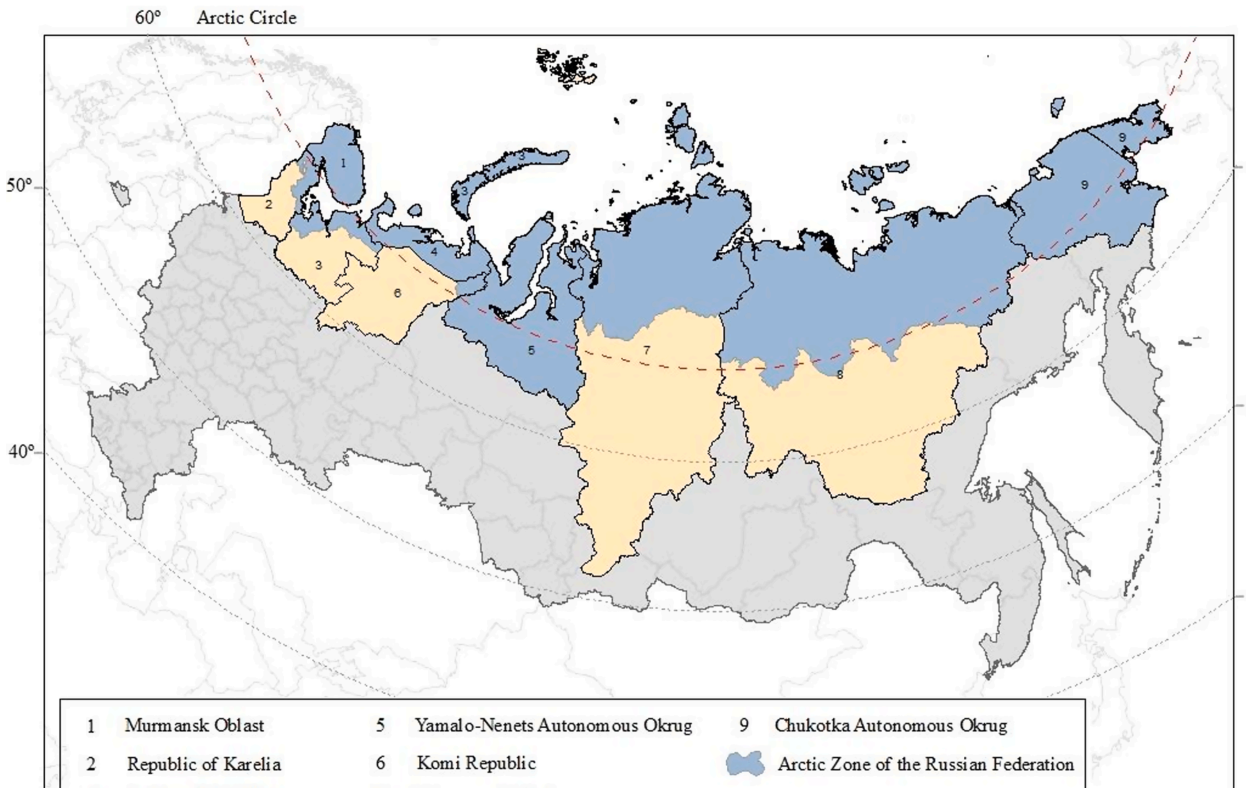

Fig. 1. Review's geographical focus as established in the Russian the Russian Presidential Decree N° 296, 2 May 2014, Land Territories of the Arctic Zone of Russia.

republics) authorities, excluding adaptation outputs reported at the local level (e.g. district towns, municipal formations).

Data collection took place in three stages, combining three different data sources normally used in tracking studies (Lesnikowski et al., 2016; Austin et al., 2019; Biesbroek and Delaney, 2020). First, we used a search string based on terms related to climate change, adaptation, and wildfires to identify potentially relevant peer-reviewed articles in Web of Science, Scopus, Russian Science Citation Index, and 11 pertinent Russian journals. Secondly, a hand-based web search was performed on official Russian government websites to identify any content or files related to climate change adaptation to wildfires. Finally, content-analysis was conducted to all submissions (n = 3) of the Russian Federation to the UNFCCC to identify potential outputs designed to adapt to wildfires. After screening over 3,000 documents, only 12 documents were included in this study. The majority of the retrieved documents were excluded as no explicit mention to climate change was found.

To check the completeness of the search, the list of included scientific articles and policy documents was presented to 11 scholars working on climate change adaptation, wildfires, and Russia. The selection of scholars was based on authorship of key articles on the topic and on our list of included adaptation outputs and included both non– and Russian native speakers. Four scholars responded, suggesting no additional outputs that met our inclusion criteria and thus confirming the robustness of the search protocol. Adaptation outputs found from peer-reviewed searches, UNFCCC submissions, and official governmental websites were cross-referenced to avoid double counting. (Fig. 2). For a detailed description on how the sources were identified, see supplementary materials.

3.2. Data analysis

The final set of wildfire adaptation outputs were documented in a detailed Excel spreadsheet and coded using a protocol identifying key impacts and risks, goals, and instrument characteristics (see supplementary material). The protocol included 23 indicators such as implementing entity, year of instrument adoption, adaptation approach, nature of climate drivers, climate models and scenarios,

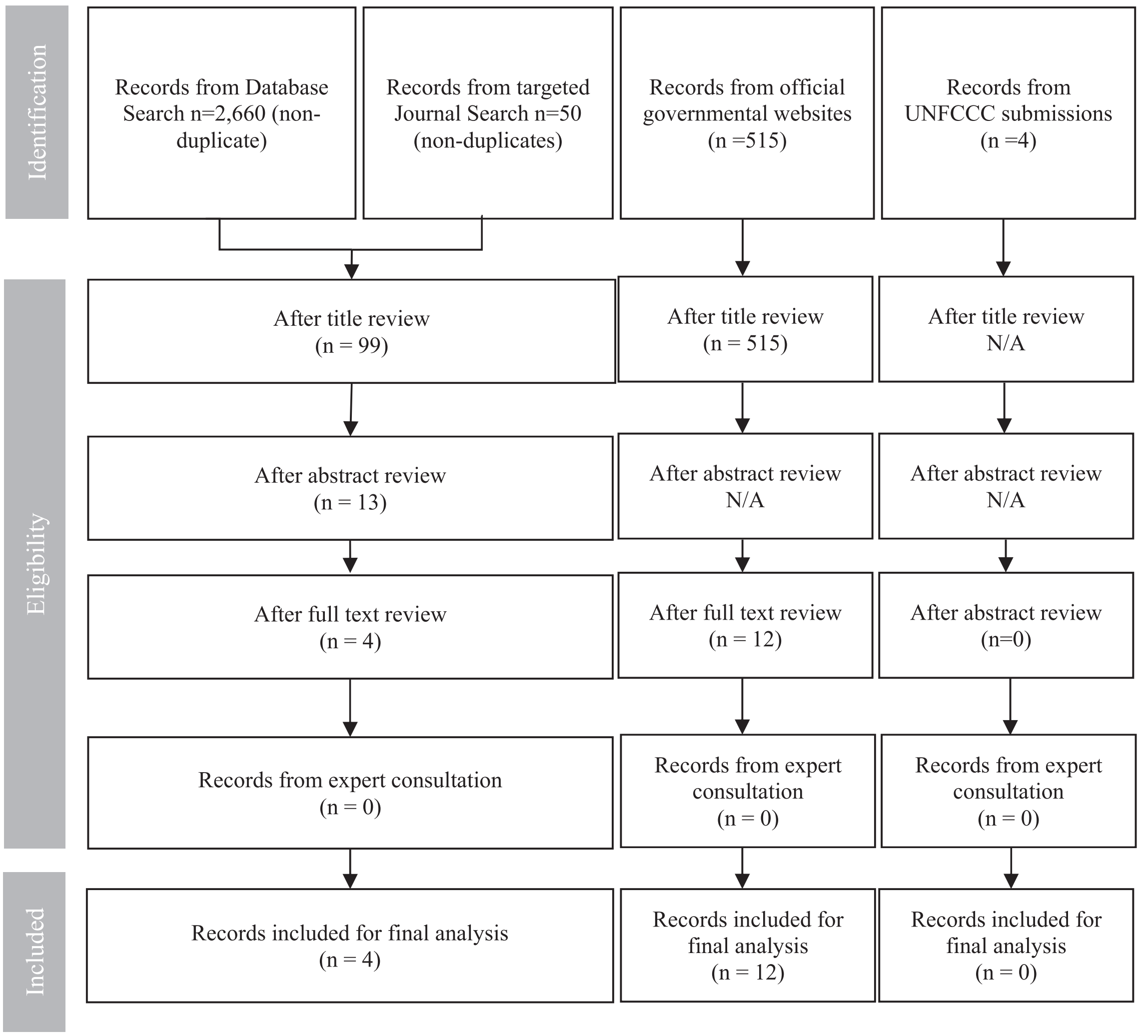

Fig. 2. Document identification, eligibility, and inclusion. Adapted from McDowell et al. (2019) and Canosa et al. (2020).

policy aim, policy implementation, policy approach, policy goal, spatial approach, nature of governing resource, policy target and target, governance level, monitoring, and consideration of vulnerable groups. Under the "nature of governing resources" indicator, adaptation outputs were catalogued using NATO typology (Hood, 1983), which has been used in many adaptation tracking studies (e.g. Lesnikowski et al., 2019): (i) information/knowledge (nodality); (ii) legislation/regulation (authority); (iii) finance (treasure); and governmental functioning (organization). Adaptations were coded for policy goals and targets: policy goals constitute the strategic policy goal (e.g. improve fire response), while policy targets constitute the specific means by which these goals will be implemented (e.g. improvement of forest tracks) (Howlett and Cashore, 2009). Furthermore, adaptation outputs were coded by the temperature (1.5, 2, 3, 4 °C) and models and scenarios (e.g. RCP, SRES) used to inform policy instruments choice. Following data entry, descriptive statistics were used to characterize and quantify information about wildfire adaptation outputs in the Russian Arctic, comparing the nature and scope of reported outputs, along with the total number of adaptations documented (i.e. adaptation intensity). The full coding scheme and associated descriptions are provided in the supplementary materials.

3.3. Limitations

Despite efforts to develop a comprehensive search syntax, this study should be read with several caveats in mind. First, the study poses some challenges regarding the comprehensiveness of the dataset as policies or programs that increase resilience or reduce vulnerability to climate change may not be labelled as adaptation, and therefore not captured by the search methods. Indeed, it is very likely that, despite not being labelled 'adaptation' per se, current wildfire policies and programs contribute to reduce the negative impacts of both ongoing and projected climate-related changes in wildfire activity. We can expect that some of these measures, however, are directed to coping and responding to ongoing changes rather than anticipating the long-term, projected impacts, consequently leading to potential maladaptive outcomes in the face of future climatic changes (Dupuis and Biesbroek, 2013; Dilling et al., 2015). Additionally, identifying policies and programs that are not labelled 'adaptation' but contribute to reduce climate change impacts remains complicated and contentious, particularly as policy outcomes are challenging to measure and adaptation actions have been argued to take many different forms (Knill et al., 2012; Dewulf, 2013; Berrang-Ford et al., 2021). We thus rely on governments to frame their actions as 'adaptation' when referring to measures that address both current and longer impacts of climate change. Comparing policy outcomes labelled adaptation with others that are not can provide crucial information on the nature of the reported adaptation outputs, particularly to determine whether these measures represent substantial changes to the status quo or only a symbolic change in the face of public perceptions. Second, local governments were also omitted in this study, despite being important players in adaptation. Future studies including local-level adaptations would complement our findings and enhance our understanding of wildfire adaptation in Arctic systems, particularly if and how adaptation is implemented and with what outcomes. Third, ministries/departments that were not included in our list may have developed wildfire adaptation outputs during our review period. Finally, this study is affected by limitations common to all systematic reviews, namely data extraction is influenced by researcher subjectivity to some extent and relevant documents may have been missed. Nonetheless, the review offers a proxy of how wildfire adaptation is occurring in northern Russia and is well suited for future comparative analysis across and between regions, for identifying general trends and patterns, and for monitoring progress over time.

Table 1
List of adaptation outputs documented between 2008 and 2020 in the Russian Arctic, by district and document year.

Jurisdiction	District	Year	Adaptation output
Federal	Russia	2017	Clarifications in the order of preparation of sections 3.11 and 4.2 of the Standard form and composition forest plan of the constituent entity of the Russian Federation
Federal	Russia	2017	On approval of the standard form and composition of the forest plan of a constituent entity of the Russian Federation, the procedure for its preparation and amendments to it
Federal	Russia	2011	On the approval of a comprehensive plan for the implementation of the Russian Federation Climate Doctrine for the period up to 2020
Federal Constituent Entity	Northwest	2018	Forest Plan of the Arkhangelsk Region
Federal Constituent Entity	Northwest	2018	Forest Plan of the Republic of Karelia for the years 2019–2028
Federal Constituent Entity	Northwest	2019	On approval of the Forest Plan of the Nenets Autonomous Okrug
Federal Constituent Entity	Northwest	2019	Forest Plan of the Republic of Komi 2019–2028
Federal Constituent Entity	Northwest	2019	Forest Plan Murmansk Region
Federal Constituent Entity	Ural	2019	On approval of the Yamalo-Nenets Forest Autonomous Region Plan
Federal Constituent Entity	Siberia	2018	On approval of the forest plan of the Krasnoyarsk Territory
Federal Constituent Entity	Far East	2019	On approval of the Forest Plan of the Republic of Sakha for the period 2019–2028
Federal Constituent Entity	Far East	2019	Forest Plan of Chukotka Autonomous District

4. Results

Twelve adaptation outputs were identified, documented, and reviewed for the 12-year study period (2008–2020) (Table 1). The adaptation outputs were mostly reported at the regional level (n = 9; 75 %) followed by the national level (n = 3; 25 %), with each federal constituent entity reporting only one adaptation policy output. The majority of reported outputs were published in 2017 or later, with the earliest one published in 2011. Between the periods of 2008–2010 and 2012–2017, no wildfire adaptation outputs were identified, even with extreme fire years in European Russia in 2010 (Krol et al., 2013) and Siberia in 2001, 2005, and 2013 (Conard and Ponomarev, 2020). It is possible that more wildfire adaptation outputs were developed but were not accessible via the web or were replaced or removed from the internet. For instance, the UNFCCC submissions refer to a methodology for calculating the risks and consequences of forest fires not available online, and thus was not included in this study. The target of the majority of reported adaptation outputs were regional entities (n = 9; 75 %), indicating the predominance of outputs reported at the regional level. This highlights the federalist political system in the Russian Federation, where national authorities establish the legislative and regulatory framework that constituent entities follow and implement. For example, state authorities of the Russian Federation are required by the Forest Code (2006) to establish fire safety requirements and measures in forests that authorities of the federal regions organize and implement in their territories. (See supplementary materials for a brief introduction to fire management in the Russian Federation).

4.1. Key climate impacts, risks, timeframes, and scenarios

The most common climate drivers listed in the Russian government documents included changing snow and rain patterns (22 %);

Table 2

Illustrative adaptations from Russian Arctic regions between 2008 and 2020, by district, policy goal, and policy target. Federal Districts based on the 2000 Decree of the President of the Russian Federation "On the Plenipotentiary Representative of the President of the Russian Federation in the Federal District".

Constituent Entity	District	Policy goal	Policy target
Murmansk Oblast	Northwestern	Improving the effectiveness of fire safety measures in forests, including forest fire prevention, monitoring of fire hazards in forests and forest fires	Creation of firebreaks Cleaning and updating firebreaks Carrying out preventive controlled burning of brushwood, forest bedding, dry grass and other forest fuels materials Installation and placement of stands and other signs and pointers containing information on fire safety measures in forests Monitoring fire dangers in forests and forest fires, aviation zone guard
		Adjustment of plans for extinguishing forest fires	No specific measures envisaged
Yamalo-Nenets Autonomous Okrug	Ural	Improving the effectiveness of fire safety measures in forests, including forest fire prevention, monitoring of fire hazards in forests and forest fires	Construction of firebreaks Cleaning of firebreaks Installation and placement of stands, signs and signs containing information on fire safety measures in forests Installation and operation of barriers, the device of barriers to limit the stay of citizens in the forests in order to ensure fire safety Monitoring of fire hazards in forests and forest fires Fire danger monitoring by aircraft Satellite monitoring of fire hazard
		Adjustment of plans for extinguishing forest fires	No specific measures envisaged
Krasnoyarsk	Siberia	Improving the effectiveness of fire safety measures in forests, including forest fire prevention, monitoring of fire hazards in forests and forest fires	Maintenance of forest roads designed to protect forests from fires Reconstruction of forest roads designed to protect forests from fires Installation and placement of stands and other signs and indicators containing information on fire safety measures in forests Clearing of glades and firebreaks and their renewal
		Adjustment of plans for extinguishing forest fires	Development and adjustment of plans for extinguishing sub-Arctic forest fires, taking into account the burning of the region
Republic of Sakha	Far Eastern	Improving the effectiveness of fire safety measures in forests, including forest fire prevention, monitoring of fire hazards in forests and forest fires	Installation and placement of stands and signs containing information on fire safety measures in forests Monitoring of fire hazards in sub-Arctic forests
		Adjustment of plans for extinguishing forest fires	Organization of ground, aviation, and satellite detection and ground and aircraft suppression

extreme and prolonged heat attributed to higher temperatures and drought (17 %); increased frequency and intensity of extreme weather events (17 %); and temperature average changes (17 %). Sometimes increased wind speeds (11 %) and increased frequency of lightning events (6 %) were key biophysical drivers of adaptation. Some documents combined multiple drivers such as drought and increased wind speeds. In others, it was unclear what types of climate risks affected or would affect forest fires in the long-term (28 %), with a general need to adapt to increased wildfire activity. No adaptation output mentioned wildfires to be affected by conditions of fuels/vegetation or thawing permafrost, which will be exacerbated due to future climate change. Only one document (Forest Plan of the Republic of Karelia for the years 2019–2028) neglected the influence of climate drivers and referred to the expansion of transport accessibility and the development of mass tourism as the main driver of adaptation. Climate risk projections or temporal scales (i.e. short, medium, long term) were not explicitly considered in any of the included adaptation outputs, with all the outputs exclusively tailored to the period of validity of the Forest Plans (2018–2028).

4.2. *Policy instruments, goals, and targets*

The majority of the documented adaptation outputs (n = 11; 92 %) were related to the elaboration and validation of the section on "Information on planned measures to preserve the ecological potential of forests, adapt to climate change and increase the sustainability of forest", included in the latest forest plans of all federal regions. It was first introduced by Russian national forestry authorities in the 2017 Order of the Russian Ministry of Natural Resources and Ecology "On approval of the standard form and composition of the forest plan of a constituent entity of the Russian Federation, the procedure for its preparation and amendments to it", which set outs how regional forest plans must be structured and developed. The specific contents of the plans as well as the specific adaptation measures were a responsibility of every regional authority. As such, Russian regions are reactively responding to the national mandate, rather than following a comprehensive adaptation planning framework. Most of the adaptation outputs (n = 11) are thus mainstreamed (integrated) into existing policies rather than developed as stand-alone plans specifically addressing climate change. The one output (n = 1; 8 %) was associated with the implementation of the Russian Climate Doctrine in 2011 (Government of the Russian Federation, 2011), when executive bodies were requested to include long-term measures to adapt to wildfires in the development and implementation of their planning documents. No evidence has been found linking the introduction of climate change adaptation into recent forestry planning efforts to the provisions considered in the 2011 Climate Doctrine.

We find a high reliance on authority (legislation, inter-governmental mandates, and regulations) to govern resources (11 out of 12 outputs). The remaining output fell under the nodal (i.e., informational) typology, consisting of an order approved by the Russian Ministry of Natural Resources in 2017 which clarifies sections 3.11 and 4.2 of the latest forest plans. There is also a high prevalence of simple policy mixes (multiple goals and one instrument) in our database (Lesnikowski et al., 2019). Most adaptation outputs (n = 11; 92 %) have two specific policy goals: (i) improve the effectiveness of firefighting, including warning of forest fires and fire hazard monitoring in forests; and (ii) adjust plans for extinguishing wildfires. These goals have been set at the national level by federal authorities, entrusting the development of specific means by which these goals will be achieved to regional authorities (Table 2). Accordingly, reducing the risk of wildfires and improving fire response is the predominant approach to adapt to wildfires in 11 and six of the reported outputs, while reducing human exposure to fires were considered in four outputs. No evidence of how adaptations are going to be implemented or monitored was identified.

Finally, vulnerable groups such as the elderly, women, children, and/or disabled persons, as well as Indigenous Peoples, were not considered in any of the adaptation outputs. This is in line with the other adaptation tracking studies where the inclusion of vulnerable peoples in policy design happened in less than 5 % of the cases (Lesnikowski et al., 2016). No differentiation between tundra and the taiga forest was documented in the reviewed outputs. We also found hardly any information on the implementation procedures allocating actors and rules. The exception here was the 2011 Order of the Government of the Russian Federation "On the approval of a comprehensive plan for the implementation of the Russian Federation Climate Doctrine for the period up to 2020″, where the implementation of wildfire adaptations was delegated to the environment, natural resource units, executive and legislative bodies, and forest planning departments. No monitoring process for documented adaptation policy instruments, strategy, and program were identified. A comprehensive presentation of the results can be found in our supplementary materials.

5. Discussion and conclusion

With the changing and intensifying Arctic fire regime, climate change adaptation policy has become a priority. The 2019 and 2020 fire seasons in the Russian Arctic offer a worrying glimpse of what a future world with increased fire activity might look like if we fail to mitigate and adapt to climate change. Efforts to understand if and how wildfire adaptation planning is occurring in northern Russia is lacking. To our knowledge, this study provides the first systematic review of the state of climate change adaptation policy and planning to wildfires in the Russian North, using a combination of three adaptation tracking approaches. Our findings demonstrate that Russia and its northernmost regions have started wildfire adaptation planning, but also highlight a number of critical shortcomings that are important to discuss below. Given the recent war in Ukraine, the results of this work represent the pre-conflict understanding of climate policies for the Russian Arctic and provide a baseline for understanding future dynamics in a changed and changing Arctic climate and geopolitical region.

Firstly, the biophysical drivers motivating adaptations are generally consistent with observed climate-related changes affecting fire regimes in northern Russia; temperature and hydrological changes related to changing snow and rain patterns. However, none of the outputs we reviewed integrated potential future projections of climate change, which suggests that reported adaptations are not informed by contextually accurate scientific information about changing Arctic systems. The reported adaptations were exclusively tailored to the period of validity of the Forest Plans (2018–2028), disregarding any potential changes that may happen in the medium to long term (greater than2030). This finding raises concerns about the long-term viability of reported adaptations, echoing observations made across the adaptation literature (Canosa et al., 2020; McDowell et al., 2019), that the impacts of climate change are being underestimated, potentially leading to maladaptive responses. To ensure implemented adaptations are consistent with potential future trajectories of climate change, policymakers in Russia should seek out and extensively engage with available scientific information when developing adaptations outputs. At the same time, when planning adaptations, it is important to integrate observations from Indigenous/local stakeholders whose familiarity with the local environment can complement scientific assessments (Ford et al., 2018).

Secondly, there has been insufficient engagement with the human dimensions of climate change. Most of reported adaptation outputs did not contemplate the role of human-ignited fires in future fire regimes, even though half of all the registered wildfires in the Russian Arctic were initiated by anthropogenic influences. Likewise, none of the reported adaptations were explicit about the role and needs of marginalized and vulnerable groups, which may in some cases contribute to maladaptation. The lack of reporting on the human dimensions of climate change brings into question the extent to which the current wildfire adaptation outputs in Russia will be able to reduce underlying inequalities that increase exposure-sensitivity and vulnerability and increase adaptive capacity to wildfires. This finding contrasts with what has been done at different governmental levels in other Arctic nations, where wildfire outputs addressing the human dimensions of climate change are evident (Hennessey and Streicker, 2011; Government of Yukon, 2017; MOA, 2019; Alaska Division of Forestry, 2020; Fire Adapted Communities Coalition, 2020). For example, the 'Climate Preparedness and Adaptation Strategy' (2021) developed by the government of British Columbia (Canada) recognises the differential impacts that wildfire smoke have on unhoused and housing insecure populations, highlighting specific actions to improve the provincial response in this regard. It is therefore important that adaptation planners in Russia recognize that different populations will have varying degrees of exposure-sensitivity and adaptive capacity to changing fire regimes, depending on cultural and socio-economic factors. Enhanced communications between Russian fire managers (federal and regional), local and Indigenous communities, non-profit organizations, the private sector, and other Arctic nations can be an effective way forward to make relevant decision makers aware of who gains and who loses from changing fire regimes and implemented adaptation policy responses (Callaghan et al., n.d.; Zamolodchikov, 2013; Shmatkov et al., 2013). This can be achieved, for example, by enhancing data-sharing and integration of citizens' views and opinions within the 'Voluntary Fire Brigade', and cooperatively develop new decision support tools, guidelines, and preparedness strategies. Further gains can also be made by researchers, practitioners, and stakeholders, who can help provide essential information to fire managers and decision makers by making marginalized groups' needs explicit as well as provide recommendations to create concrete provision to address their needs.

Thirdly, the lack of adaptation outputs addressing the differentiated structural and pyrogenic characteristics of taiga and tundra forests indicates that adaptation outputs in all Russian regions are overlooking critical context-specific and place-based climatic exposures, and thus not targeting realistic processes of change (Shur et al., 2020). All of the adaptation outputs were developed to manage fires occurring in sub-Arctic boreal forests, overlooking fires in the treeless tundra region. This carries the risk of increasing the adverse impacts of climate-induced wildfires, as well as missing new opportunities, as increase in fire activity in the Russian tundra are projected for this century (Chen et al., 2021; Holzworth et al., 2020). Carbon emissions from wildfires could significantly accelerate under future scenarios of climate change if tundra-specific adaptation outputs are not developed or implemented (Mack et al., 2011). Burning of the Arctic tundra could also catalyse other biogeochemical and biophysical changes if left unmanaged, such as permafrost thaw; increase human health and safety impacts from smoke pollution; and limit new economic opportunities in the forestry sector associated with the transition from tundra to taiga forests (Heim et al., 2019; Pan et al., 2011). Similarly, land-managers and policy makers therefore need to include tundra fires in their adaptation planning and tailor current fire management practices and land-use planning approaches to the tundra region, building upon current fire trends and anticipation of the changes projected with climate change. When developing wildfire adaptation outputs for the tundra region, particular attention should be given to potential trade-offs between fires' ecological role and their socioeconomic impacts. Similarly, current firefighting techniques used in the boreal forest may not be appropriate for the more fragile Arctic tundra, requiring innovative fire management approaches and methods.

Notwithstanding the shortcomings outlined above, the majority of reported adaptations were mainstreamed into existing policy instruments such as forest plans, which has been identified in the adaptation literature as the most effective way to reduce vulnerability and adapt to climate change; promote innovation; and distribute resources from an administrative and budgetary point of view (Lorenz et al., 2017; Rauken et al., 2015; Runhaar et al., 2018). The prevalence of authority instruments in our dataset indicates a mandate from Russian policymakers to stimulate adaptation, implement specific policy objectives, and move forward in the climate change agenda in meeting the challenge of adapting to wildfires in Arctic systems. However, the lack of nodal and organisational instruments – both integral components for informing and preparing adaptation outputs (Lesnikowski et al., 2019) – questions whether planned policies and measures are suitable in the long-term; we note, however, that these efforts may have been conducted but not yet reported or published online. Adaptation outputs were also developed relatively recently, which indicates that experiences in understanding the effects of planned measures is yet to develop. The lack of information on how adaptations are going to be implemented and/or monitored can here prove problematic in the future, particularly for measuring the performance and evaluating and measuring the effectiveness of adaptation outputs. Thus, research addressing how reported adaptations will be implemented in practice is very much needed for future works.

Our final observation is that the nature and extent of documented wildfire adaptation outputs in Russia are not sufficient to address the seriousness and severity of climate change. Despite efforts to adapt to increased wildfire activity in the Russian Arctic, key shortcomings were found in relation to the scientific, human, and policy management characteristics of documented adaptation outputs, all of which puts into question whether reported adaptation outputs are sufficient in meeting increased wildfire activity in the Russian Arctic. These shortcoming can be overcome with political will, institutional change, financial support, creative management, and by individual or collective efforts but there are many factors constraining adaptation, including an absence of political leadership on adaptation in the Russian Federation, unclear or ill-defined responsibilities, the existence of other pressing socio-economic problems, lack of financial resources and lack of technical data on future climate risks (FAO, 2012; Sharmina et al., 2013; Skryzhevska et al., 2015). Nevertheless, existing pan-Arctic intergovernmental forums, such as the Arctic Council, are well placed to catalyse the attention of policymakers to address the challenge of adapting to wildfires in the Russian Arctic, driven by knowledge co-production and continuous information and resource exchanges. Indigenous, traditional, and local communities who are the first in experiencing the impacts of wildfires must play a critical role in leading and contributing to these efforts. Moreover, further collaborative, inclusive, and multidisciplinary studies are needed to inform and develop effective and place-based and context-specific suitable wildfire adaptations for the Russian Arctic. Key research needs include improving our understanding on how climate is changing and the impacts it is having on wildfires throughout the Russian Arctic; assess how people manage changing fire regimes and what factors affect this; and examine opportunities for adapting to changing wildfires. Developing such a knowledge base is both necessary and a priority.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Author contributions

IVC coordinated the review, created and designed the figures, tables, and supplementary materials, and wrote the manuscript. RB, JF, JLM, RO, JP, and DB provided guidance on manuscript organization and contributed to the interpretation of the findings and writing of the manuscript.

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Data availability

The data used in this review is publicly available.

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