Investigating the recommendations and governmental actions to address the emerging risks of vector-borne diseases in Canada's changing climate: A scoping review

Renée Schryer [1¶], Michala Norman [1¶], Manisha A. Kulkarni [1]

1 School of Epidemiology and Public Health, University of Ottawa, Ottawa, Canada

¶ These authors contributed equally to this work.

Abstract

Climate change is expected to increase the risks associated with vector-borne diseases, and its implications for human health are already observed across Canada. The objective of this review was to investigate the recommended adaptation strategies related to the risks associated with vector-borne diseases and examine how various levels of government in Canada are executing these recommended actions in their climate change adaptation plans. A combined methodology was employed, consisting of two distinct searches to examine both the recommended adaptation strategies in the peer-reviewed literature and the adaptation actions from governmental sources in the grey literature. Relevant sources were identified across four databases (Embase, Medline, Scopus, Global Health), as well as national, subnational, and municipal governmental websites across Canada. Data were categorized into eight (8) specific adaptation categories based on previously established frameworks. Data were also collected on which vector-borne diseases were referenced, the vulnerable population groups considered, and the inclusion of a One Health focus. A total of 194 peer-reviewed articles and 87 grey literature sources were reviewed, which contained a total of 582 adaptation recommendations and 178 adaptation actions. The most frequently proposed adaptation strategies related to the following categories: *Management, Planning, and Policy*, *Information and Research*, and *Warning and Observation Systems*. Our findings revealed a strong alignment between the recommended strategies and the adaptation measures being implemented. However, notable discrepancies were present among the adaptation categories of *Practice and Behaviour* and *Laboratory Methods and Other Tools*, revealing gaps across the literature and potential opportunities for further action. While many recommended strategies are being incorporated into actions across Canada, significant regional variability and gaps remain. We advocate for an increased investment in adaptation measures targeting vector-borne diseases and a greater integration of the One Health approach in subnational and municipal plans.

Introduction

The effects of climate change on human and natural systems are predicted to have a significant impact on human health globally, including in North America (1,2). One of the projected health impacts is the emergence and increase in incidence of vector-borne diseases (VBDs). Substantial evidence has underscored the role of rising temperatures, altered precipitation patterns, and extreme weather events in influencing vector distributions (1,2). These changing conditions are expanding habitable areas for vectors such as ticks and mosquitoes, among other changes, further accentuating the potential impact on public health (1,2). In Canada, these climate impacts are already being observed, with data linking the northward expansion of tick vector species to rising temperatures, and the subsequent rise in the incidence of Lyme disease (3,4).

Scientific findings from the Synthesis Report (SYR) of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) show that the global surface temperature has increased by approximately 1.1^{o}C during 2011-2020 in comparison to 1850-1900 (5). Based on the historic and current data on greenhouse gas (GHG) emissions, these global warming changes have been primarily influenced by human activities (5). Global responses to reduce the impacts of climate change on health include mitigation actions to reduce GHG emissions, and adaptation actions to reduce health risks by reducing population exposures and enhancing resilience (6). Despite advancements in adaptation planning and implementation across various sectors and regions, the success of these efforts is largely dependent on the capacity and efficiency of governance and decision-making processes, as emphasized by the IPCC (6).

Trends have indicated that Canada is warming at a rate that exceeds the global average (7). As the world's second-largest country, Canada encompasses a vast array of geographies and environments (7). Consequently, the impacts of climate change and the associated risks of VBDs are expected to vary significantly across its diverse regions (7). While recognizing the inequities in health system access and outcomes across provinces and territories in Canada, it is crucial to understand the various adaptation measures designed to mitigate climate risks and reduce vulnerability (6). Identifying key populations at risk remains complex, compounded by the multi-jurisdictional nature of government, presenting an opportunity to develop targeted responses that address specific regional needs and vulnerabilities (6,7).

To address these foci, we conducted a scoping review to investigate the recommended adaptation strategies to address the emerging risks of VBDs in the context of climate change and examine how various levels of government across Canada are incorporating these strategies into their climate change adaptation plans. The question guiding this scoping review was, "What adaptation strategies are being recommended to effectively mitigate the emerging risks associated with VBDs in Canada, and how are governments incorporating these recommendations into their climate change adaptation plans?". Additionally, we sought to investigate the integration of a One Health approach and the consideration of vulnerable populations in adaptation actions, as outlined in the following sub-questions:

1. How are governmental adaptation plans strengthening efforts in a multisectoral and interdisciplinary approach through the emerging paradigm, One Health?
2. Are governmental adaptation plans specifically including a consideration for health equity or populations who may be at increased risk for VBDs?

Methods

We conducted a comprehensive scoping review employing a combined methodology of two distinct searches to examine both peer-reviewed and grey literature, with an aim to meet our outlined research objectives. We adhered to the methodology outlined in the PRISMA-ScR extension for scoping reviews (PRISMA-ScR) (8). The protocol for this review was registered on OSF Registries on July 10, 2024 (https://osf.io/9dbjg).

Eligibility criteria and search strategy

The peer-review literature search identified recommended vector-borne disease specific climate change adaptation strategies. These recommendations were derived from both qualitative and intervention studies, consisting of plans, strategies, or actions suggested or proposed from a subject matter- expertise perspective. A search was conducted on July 18, 2023, across the following databases to identify relevant sources: Embase, Medline, Scopus, Global Health. The search queries for each database are shown in the Supplementary Information (S1 Table). Articles were included and excluded based on the criteria outlined in Table 1.

Table 1. Inclusion and exclusion criteria for peer-reviewed literature.

Category	Inclusion	Exclusion
Concept	- Articles on climate change AND recommended adaptation strategies to adapt to emerging risks posed by VBDs.	- Articles on climate change AND recommended adaptation strategies that do not consider VBDs. - Articles with recommended strategies

	- Articles on tick-borne OR mosquito-borne diseases (ex. Lyme, West Nile).	that do not explicitly mention climate change.
Source of Evidence	- Primary research; reviews; scholarly literature, commentaries, conference proceedings, editorials, reports, essays, and case studies.	
Language	- Articles in English.	- Articles in other languages.
Publication Year	- Articles published during any time period.	- No restriction.
Publication Status	- Online articles published or in-press.	- Pre-print articles.
Geography	- Articles where the geographical focus is clearly a North American or global context.	- Articles where the geographic focus is a non-North American country.

For the grey literature, searches were conducted to identify current documents and plans from governments across Canada. Climate change adaptation plan documents with a consideration of VBDs were examined across governmental websites based on the inclusion and exclusion criteria in Table 2. Proposed climate change adaptation initiatives from multiple levels of government were investigated, including national, subnational, and the ten largest population centers (see Table 3 for a summary of the specific regions and corresponding two-letter abbreviations). A Level 1 search, conducted internally through the governmental website, or a Level 2 search, conducted through Advanced Google, was employed and recorded for each region shown in the Supplementary Information (S2 Table). Search terms were relevant to the concepts of climate change, adaptation and VBDs.

Table 2. inclusion and exclusion criteria for grey literature.

Category	Inclusion	Exclusion
Concept	- Documents published (internally or externally) on a national, provincial, or municipal level website that highlight VBDs or infectious diseases in their climate change policy and adaptation plans. - Governmental documents on tick-borne OR mosquito-borne diseases with outlined adaptation strategies or actions.	- Documents published (internally or externally) on a national, provincial, or municipal level website that do not highlight VBDs or infectious diseases in their climate change policy and adaptation plans. - Documents with outlined adaptation strategies or actions that do not explicitly mention climate change.
Source of Evidence	- Documents in URL or PDF format.	

Language	- Articles in English.	- Articles in other languages.
Publication Year	- Articles published during any time period.	- No restriction.
Publication Status	- Public documents.	- Documents that are inaccessible to the public.
Geography	- Articles where the geographical focus is clearly related to a Canadian context.	- Articles where the geographic focus is not related to a Canadian context.

Table 3. Summary of regions and corresponding abbreviations included for grey literature.

National Level	Subnational Level	Municipal Level
Canada (CA)	Alberta (AB) British Columbia (BC) Manitoba (MB) New Brunswick (NB) Newfoundland and Labrador (NL) Northwest Territories (NT) Nova Scotia (NS) Nunavut (NU) Ontario (ON) Prince Edward Island (PE) Quebec (QC) Saskatchewan (SK) Yukon (YT)	Toronto Montreal Vancouver Calgary Edmonton Ottawa Winnipeg Quebec City Hamilton Kitchener

Extracted data included adaptation strategies classified by a recommendation (peer-reviewed literature) or an action (grey literature), which were organized into eight (8) discrete categories. These categories were initially established using the existing titles outlined in the original framework by Austin et al. (2015); to these, the categories *Laboratory Methods and Tools* and *Physical Infrastructure*, were constructed based on the analysis by Biagini et al. (2014). Lastly, *Other Strategies* were incorporated as an additional category to capture the full range of adaptation options within the literature (9,10). See Table 4 for a comprehensive description of each category. As an example, recommendations or actions involving the implementation of vector control strategies, use of biological or chemical management techniques or personal protective measures, were categorized under *Practice and Behaviour*. Additional data on the specific VBDs mentioned, considered vulnerable population groups, and discussions surrounding the concept of One Health were also collected.

Table 4. Defined categories for adaptation strategies with examples.

Adaptation Category	Examples
1) *Management, Planning and Policy*	- Legislation and policies - Use of frameworks - General funding or investments - Collaboration or coordination - Development of new working groups

2) *Practice and Behaviour*	- Vector control mechanisms (ticks or mosquitos) - Reduction of standing water - Personal protection
3) *Information and Research*	- Increasing an evidence base - Development of research programs - Communication tools - Identifying research priorities
4) *Capacity Building*	- Training or education in any form - Investments in public health and institutions - Building community or healthcare capacity
5) *Physical Infrastructure*	- Revegetation - Park or landscape management
6) *Warning and Observation Systems*	- Monitoring and surveillance systems for VBDs, vectors, climate or weather - Early warning systems
7) *Laboratory Methods and Other Tools*	- Developing molecular methods for vector control - Diagnostic testing - Development or use of modeling tools
8) *Other Strategies*	- Any other strategies not aligning with the above categories

Screening and study selection

Peer-reviewed search results were imported into Covidence software (Veritas Health Innovation, Melbourne, Australia; available at www.covidence.org) to screen and manage the results of the search. The titles and abstracts of each article were screened and considered for full-text review by two independent reviewers to determine their adherence to the inclusion criteria. Any conflicts were resolved through discussions with a third reviewer. Microsoft Excel was used to systematically record information from sources identified by the grey literature search.

Data extraction

Information extracted from sources included study characteristics, geographic focus, article type, type of VBDs mentioned, discussion of One Health, and adaptation strategies. For the grey literature search, the data extraction procedure additionally included the respective level of government, the webpage searched to locate the source or document, and the hyperlink (if applicable).

Results

Search results

From the peer-reviewed literature search, 2970 sources were imported for screening, and 1101 duplicates were removed. A total of 1869 studies were screened for title and abstract, and 284 full-text studies were assessed for eligibility. Out of these, 90 studies were removed; most did not include VBDs or recommended adaptation strategies (n=24) or were outside of the geographic scope (n=20). A total of 194 peer-reviewed articles were included, consisting of primary research (23.83%), reviews (48.19%), books or chapters from scholarly literature (7.25%), and other sources (20.73%) such as commentaries, conference proceedings, editorials, reports, essays, and case studies. The geographical distribution of these sources was as follows: Canada (20.7%), the United States (20.2%), North America as a whole (1.6%), global (41.2%) or a combination of multiple regions (16.58%). See Fig 1 for a detailed summary of the PRISMA flow chart.

Fig 1. PRISMA flow chart.

From the grey literature search, 87 relevant documents and sources were identified from selected governmental websites. Within these sources, 20 were national (23.0%), 41 were subnational (47.1%), 22 were municipal (25.3%), and 4 were regional (4.6%). A summary of these results is presented below in Fig 2.

Fig 2. Summarized search results by proportion (%) from grey literature sources. Percentage distribution by A) Level of government (n=87) B) Province/territory (n=40) C) Municipal region (n=23). Subnational region abbreviations: Alberta (AB), British Columbia (BC), Manitoba (MB), Newfoundland and Labrador (NL), Northwest Territories (NT), Nova Scotia (NS), Nunavut (NU), Ontario (ON), Prince Edward Island (PE), Quebec (QC), Saskatchewan (SK), and Yukon (YT).

Based on the adaptation classification system, 582 recommendations were extracted from the peer-reviewed articles, and 178 adaptation actions were extracted from the sources and documents from the grey literature search. Fig 3 presents a comparison of the proportions of these adaptation strategies across each of the eight adaptation categories previously described. See the Supplementary Information for a complete summary of the extracted recommendations (S3 Table) and actions (S4 Table) from the peer-reviewed and grey literature.

Fig 3. Comparison of the proportion of climate change adaptation recommendations related to VBDs for total number of entries by category for peer-reviewed and grey literature.

Types of VBDs

The types of VBDs referenced in the adaptation strategies differed greatly between peer-reviewed and grey literature (see Fig 4). This finding corresponds to the inclusion of North American-focused and global articles in the peer-reviewed literature search, while the grey literature search targeted specific Canadian geographies. Peer-reviewed sources emphasized a wide range of non-endemic VBDs (to Canada), addressing both tick- and mosquito-borne diseases including Dengue (n=90), West Nile fever (n=90), Malaria (n=90), Lyme disease (n=77), Chikungunya (n=51), Yellow Fever (n=43), Zika (n=41), Leishmaniasis (n=17), Chagas (n=12), Schistosomiasis (n=12), among others (n=100). In contrast, grey literature focused more broadly on VBDs (n=59) without a specific reference to a particular disease among the adaptation actions outlined in governmental plans. Notably, the most frequently cited endemic VBDs in grey literature were Lyme disease (n=32) and West Nile virus (n=26).

Fig 4. Types of VBDs referenced A) Peer-reviewed literature and B) Grey literature.

The Consideration for Vulnerable Populations and Health Equity

Discussions highlighting the importance of considering vulnerable populations and health equity in climate change adaptation for VBDs were present in 74 (38.1%) peer-reviewed sources and 38 (43.7%) governmental documents from the grey literature. There was a diverse range of vulnerable groups mentioned across these discussions (see Fig 5). In the peer-reviewed literature, the most frequently cited groups included older adults and seniors (n=22), children and youth (n=22), those with low-income (n=22), vulnerable populations in general (n=19), and those living in urban, rural or remote regions (n=15). In contrast, governmental actions from the grey literature focused more on vulnerable populations in general (n=12), Indigenous communities (n=10), those with health conditions or disabilities (n=9), older adults and seniors (=8), and children and youth (n=8).

Fig 5. Vulnerable populations mentioned in peer-reviewed vs. grey literature vs. by group.

Category #1: *Management, Planning and Policy*

Adaptation strategies classified in Category #1 include those related to management, planning, or policy such as legislation, funding, or collaborative groups. This category was the most frequently recommended among peer-reviewed articles, present in 131 (67.53%) of the included sources. The most prevalent recommendations included multi-sectoral collaboration and coordination with an emphasis on partnerships, cooperative effort between stakeholders, networking among public health jurisdictions, and accountability in governmental institutions (11–33). Recommendations in this category also largely focused on investing in planning or development, financial incentives or funding, and the allocation of resources to climate change adaptation efforts (2,14,15,24,30,34–39). Other notable recommendations focused on monitoring and evaluating activities, adopting a One Health approach, and improving political commitment to actions (12,19,21–23,25–27,40–49).

This category was also most frequently cited among the grey literature, present in 60 (68.97% of the included sources. Multisectoral or multidisciplinary collaboration and coordination was largely represented in the proposed and executed plans across all governmental levels (50–62). National-level initiatives focused on a collaborative approach with respect to targeted investment in Lyme disease initiatives (60). Provincial and territorial (NB, NT, ON) and municipal (Toronto, Vancouver, Winnipeg) strategies highlighted fostering partnerships with non-governmental organizations, agencies, and intuitions in their adaptation actions (50–53,58,63). Other adaptation plans related to this category involved consultation with diverse stakeholders to address climate change related risks (55,59,60). Funding relevant climate change adaptation plans were primarily discussed by the federal government (CA) (62,64–66).

Category #2: *Practice and Behaviour*

Recommendations relating to the practices and behaviours to address VBDs, such as direct vector control methods, were present in 66 (34.02%) of the included peer-reviewed articles. Most of these recommendations centered on control measures to reduce vector populations and human exposures for both endemic and non-endemic VBDs (16,17,24,43,67–77). These strategies involved the application of pesticides and biological control agents, indoor residual spraying, and the use of insecticide-treated nets (16,17,24,43,67–77). Developing more effective disease prevention strategies by combining vector control measures via integrated vector management was also highlighted as a strategy (33,78–82). Additionally, recommendations emphasized the need to link control efforts with surveillance data to inform public health activities and respond to risks related to VBDs (62,64–66,83).

From the grey literature search, this category was discussed in 8 (9.2%) of the included documents and sources. These initiatives involved engaging and partnering with stakeholders to enhance existing policies and practices (Edmonton) and adapting to climate-related threats by identifying risks and assessing vulnerability to VBDs (Pilot Infectious Disease Impact and Response Systems program, CA) (84). Other activities largely discussed preventing disease transmission, equity-based adaptation strategies, targeted practices for Lyme disease, and promoting risk management (55,85–87).

Category #3: *Information and Research*

The category of *Information and Research*, defined as any recommendation that centers around the need for specific research or evidence generation, and the creation and dissemination of information, was the second most prevalent category, present in 126 (64%) of included peer-reviewed sources. These recommendations were primarily focused on developing communication strategies, conducting vulnerability and risk assessments, and improving research to understand the distribution of vectors and transmission of VBDs (9,11,16,17,21,26,28,29,36,46,49,88–112). Recommended strategies proposed the creation of transparent, educational, and evidence-based messaging to communicate relevant information about VBDs to the public (14,20,37,45,76,80–82,84,85,90–92,113–116). The implementation of various assessments was recommended to assess the vulnerability and risk of populations associated with climate change impacts (9,11,26,28,36,49,88–99). These sources also recommended research aimed to understand environmental factors that influence vector distribution and disease transmission (9,11,26,28,36,49,88–99).

This category was also the second most frequently discussed in 40 (45.98%) of included documents and sources from the grey literature. The assessment of the local health risks of climate change was conducted both on the subnational level (BC, NB, NT) and the municipal level (Toronto, Montreal, Hamilton, Kitchener) which included a primary focus on the understanding of Lyme disease, vulnerable populations, and identifying favourable climate conditions (50,51,117–124). Establishing priorities for future research were also highlighted by NB and NT (117,125). NT emphasized investing and committing to interdisciplinary and wildlife-focused research to build an evidence base on the impacts of VBDs in the context of climate change (120,126,127). Activities to support research activities included building research groups (such as the Canadian Centre for Climate Services, Climate Science 2050, the Infectious Disease and Climate Change Program, and Lyme Disease Research Network), developing research tools, and strengthening research more broadly (54,86). Many reports also identified the need for future research (CA, NS, YT, Vancouver, Hamilton) in the following areas: best practices for VBDs, climate data, Lyme disease (including genetics, prevention, and control), and impacts of climate change on wildlife (52,54,56,60,61,63,84,86,128–130). Communication improvements and commitments to sharing information about the issue were reported by CA, NT, Toronto, Hamilton, and focused on communication modalities (such as radio, Service Canada centres, social media, publications, plain-language summaries, online central repositories, and other existing channels) to connect with a wide range of audiences including Indigenous communities, governmental stakeholders, academic partners, and marginalized and racialized groups (121,127,128,131,132). The federal government (CA) also developed education materials for Lyme disease (Canadian Federal Framework) and made commitments to supporting the generation of similar materials (86).

Category #4: *Capacity Building*

Recommendations surrounding *Capacity Building* included education, training, and building healthcare or public health capacity, and were present in 70 (36.08%) included peer-reviewed sources. The most frequent recommendations centered on educating the public and healthcare professionals on VBDs and climate change while working to strengthen health systems (2,10,14,16,22,23,27,37,42,50–52,68,69,71,76,78,82,89,93–109,116). Suggested strategies were directed towards the general public which involved educating and raising awareness about VBDs and general health impacts of climate change (2,17,24,28,69,70,72,92,97,112,133–141). Education for healthcare professionals included the previous, in addition to enhancing engagement in health research and policy evaluation to address climate change (2,38,43,70,90,97,106,133,138,141–147). Strengthening health systems and public health infrastructure was also recommended to respond to climate changing risks and for monitoring vectors and VBDs (11,15,23,43,69,89,97,99,102,138,143,148,149).

This category was also discussed in 25 (28.74%) included grey literature sources. Activities for enhancing education for the public and healthcare professionals were discussed and implemented by both provinces (ON, SK) and municipalities (Toronto, Montreal, Hamilton), with a focus on raising awareness of the health and other impacts of climate change, Lyme disease, and other VBDs (51,58,128,150,151). Building capacity by empowering youth and engaging them in climate change related actions were also included in initiatives in subnational level plans (YT) (56,63,152). Other initiatives at the subnational and municipal level involved commitments to increase public awareness and providing education and outreach materials to communities (NT, YT, Montreal, Ottawa) (65,123,126,152,153).

Category #5: *Physical Infrastructure*

The category of *Physical Infrastructure* included any recommendations with a focus on managing, designing, or adapting physical infrastructure including urban areas or parks. These were present in 15 (7.73%) of the included peer-reviewed articles. These strategies primarily focused on environmental water management and urban or housing design (15,18,23,41,49,134,135,140,154,155). It was suggested that infrastructure should be designed and adapted to respond to flooding and rising sea levels to control mosquito breeding sites (23,49,134,135,140,155). Housing quality and air conditioning was also a recommended strategy in urban design for preventing exposure from VBDs (15,18,41,154).

This category was discussed in 3 (3.45%) of the grey literature sources. These activities involved contributing to climate change related community land-use planning (Atlantic Region Adaptation Science Adaptation Science Activities, NB) and building climate-resilience via investments in infrastructure (NT) (64,117).

Category #6: *Warning and Observation Systems*

Recommendations relating to *Warning and Observation Systems* were present in 103 (53.09%) included peer-reviewed articles. These included strong emphasis on recommendations to develop and utilize early warning systems (EWS), with an emphasis on a global warning and response network (2,16,22,31,75,96,103,135,139,140,144,156–164). It was also recommended that surveillance be enhanced through increased investment and improvement, particularly in outbreak investigations. Suggestions involved updating systems, tailoring approaches to specific contexts, and extending the duration of surveillance efforts, with a focus on nationalizing these practices and ensuring actionable results (16,19,21,22,24,34,36,38,41,47,72,88,90,97,99,106,109,111,112,138,144,148,149,162,165–172). Recommended areas for enhanced surveillance include animal and wildlife, global, baseline, occupational, entry points (such as seaports and airports), and the effectiveness of interventions (29,43,46,73,76,105,113,163,173–175). Suggested methods surrounding surveillance involved passive or citizen-driven, community or population-based, disease-specific approaches, and the use of new technologies (115,176,177). It was proposed that surveillance efforts should be integrated, combining traditional vector and vector-borne disease monitoring with environmental and veterinary surveillance (17,19,24,29,34,43,73,75,91,96,102,107,144,155,164,178–183). Furthermore, incorporating new technologies, including artificial intelligence, was highlighted as a means to advance surveillance initiatives (2,68,77,102,105,145,184–189).

This category was discussed in 34 (39.08%) of included documents and sources from the grey literature. Activities and plans outlined strategies for enhancing monitoring by detailing improvements, expansions, focus areas, and refinements. CA, NB, and ON discussed how monitoring programs were being improved via increasing accessibility, enhancing activities, and incorporating a One Health lens (50,58,84,86,132,190). Expanding surveillance programs is being accomplished by focusing on cross-jurisdictional (CA, ON), nationalized (National Microbiology Laboratory, National Notifiable Disease Surveillance System, National Lyme Disease medical surveillance, CA), and expanded surveillance networks (QC) (4,59,87). Many jurisdictions highlighted the monitoring of specific climate change and indicators of VBDs. This included surveillance of specific species of concern (NT), emerging human and wildlife diseases (NT), suitable habitat areas (NT, SK), VBDs and vectors (NL, NT, SK, YT, NL, Toronto), meteorological and climate related factors (CA, QC), sentinel animals (CA), cases of disease (Ottawa, CA), and economic costs associated with VBDs (CA) (4,51,54,86,120,121,127,130,132,150,191–197). Other reported aspects of surveillance included coordinated approaches and responses in surveillance networks (NB), considering health risks (NB, Kitchener), frequent reporting and alert systems (NT), established annual surveillance activities (SK), and including specific communities (e.g., Indigenous) in monitoring and surveillance efforts (CA, YT, YT/NT/NU) (50,54,117,124,126,191–193,198,199).

Category #7: *Laboratory Methods and Other Tools*

Recommendations relating to *Laboratory Methods and Other Tools*, which broadly included any methods related to laboratory activities, field research, clinical diagnosis and management, and other tools related to VBDs, were present in 62 (31.96%) included sources from peer-reviewed literature. Recommendations in this category highlighted the need to develop new genetic and laboratory technology, insecticides, vaccines, therapeutics, and diagnostics (2,41,82,90,104,105,108,171,200,201). There was also emphasis on developing and utilizing tools such as 3D visualization, mapping, GIS, remote sensing, and other methods such as wastewater detection for VBDs (16,21,74,109,168,175,185,187,202–204). Designing and implementing tools for decision making and reporting were also strongly highlighted (2,40,42,172,205–207). Other recommendations included the use of machine learning and artificial intelligence to understand vectors, transmission cycles, and analyze relevant data (2,104,111,143,169,208,209).

This category was also discussed in 8 (9.2%) of the included grey literature sources. Identified activities included the provision of resources and tools (from the federal government to local public health professionals), and the development of new diagnostic and laboratory technologies at the national level (4,84). Additional specific disease interventions included developments in mosquito and larvae trapping methods for West Nile Virus and laboratory diagnostics for Lyme disease, both from the national level (CA) (86,132).

Category #8: *Other Strategies*

Other strategies that were not identified under the previous categories were present in 9 (4.64%) included peer-reviewed articles. These recommendations included the consideration of equity in adaptation strategies, such as minimizing risks for vulnerable populations and addressing socio-cultural barriers to adaptation, in addition to the formal recognition of climate change adaptation co-benefits (102,210,211).

This category was not recorded in any of the included sources from the grey literature.

Utilization of a One Health Lens

In the peer-reviewed literature, 24 (12.4%) sources recommended adopting a One Health approach. Similarly, in the grey literature, 8 (9.2%) governmental plans emphasized the use of a One Health framework. Of these, the majority (87.5%) were referenced at the federal level (CA), while 1 (12.5%) plan mentioned One Health the provincial/territorial level (ON).

Discussion

Concordance and Discordance of Recommendations and Governmental Actions

This review highlights the extensive range of existing recommendations for climate change adaptation in response to the emerging risks presented by VBDs. Notably, it identifies that federal, provincial/territorial, and municipal governments across Canada are actively recognizing and addressing these risks in their climate change adaptation plans. Both the proposed recommendations and implemented actions consistently fell into three key categories: *Management, Planning, and Policy* (Category #1), *Information and Research* (Category #2), and *Warning and Observation Systems* (Category #3). At a broader level, there is a clear alignment between the recommended strategies and the adaptation measures being undertaken by governments across various levels in Canada (Fig 2).

The largest discrepancies between the recommendations and the implemented actions were found within *Practice and Behaviour* (Category #2), and *Laboratory Methods and Other Tools* (Category #7). The portion of recommendations in these areas are not reflected equally in the adaptation actions. A notable gap in Canada's adaptation plans is the lack of detailed environmental control mechanisms and specific targets for VBDs under Category #2. Although the literature offers recommendations for both methods (e.g. chemical and biological control) and targets (e.g. mosquito breeding sites, mosquito replication, introduction of novel agents), these were not incorporated into the reviewed governmental adaptation plans. Similarly, specific actions relating to promoting individual measures, particularly in occupational settings, were missing. While environmental control activities may be taking place, their integration into outlined climate change adaptation plans was notably absent. Moreover, the reviewed adaptation plans did not address the use of novel technologies for monitoring and predicting the spread of VBDs (Category #7), another key area emphasized in the literature. Numerous sources recommend employing predictive modeling, remote sensing, GIS, AI, machine learning, mapping technologies, and 3D visualizations to better understand and predict the dynamics of VBDs. As these technologies become more widespread, particularly the use of AI, it will be worth observing whether their inclusion in adaptation plans increases over time.

The reviewed literature also underscored the need for strong management in climate change adaptation, particularly regarding leadership, advocacy, and collaboration across leadership groups, accountability, and responsibility. While these elements are crucial for driving meaningful action, they were notably absent from the governmental plans examined. Additionally, the literature calls for a range of both targeted and broad research initiatives, including studies on weather and climate, new tool development, and research specific to VBDs. While research may not necessarily be conducted at the governmental level, this area is still underrepresented in the current adaptation plans.

The literature also highlights the importance of robust information gathering to inform effective adaptation strategies. This includes conducting geographic analyses, evaluating adaptation capacity costs, assessing health impacts, and analyzing communication strategies—none of which are explicitly addressed in the existing plans. Although education is featured in many plans, specific recommendations for educating patients and policymakers about the impact of climate change on VBDs are missing, as are recommendations related to capacity building, particularly in vulnerable regions.

In terms of physical environmental controls, the literature advocates for improving sanitation, managing environmental water, and using prescribed burns to reduce tick populations. A broader focus on structural elements, such as urban design and improving living conditions for migrant populations, is also recommended but not incorporated into the adaptation plans. Additionally, various surveillance approaches are highlighted in the literature, including combinations of surveillance systems and modalities. For instance, three studies recommended passive or citizen-based surveillance interventions, yet these methods are not explicitly identified in any governmental plans.

Characterizing the Landscape of Canadian Adaptation Actions

Regional Differences

In examining climate change adaptation plans at the national, subnational, and municipal levels, there was an uneven distribution across regions spanning multiple areas. Notably, there was a relative overrepresentation from the territories (YT/NT/NU), which accounted for over 30% of all provincial and territorial documents. This aligns with the well-documented uneven distribution of rising temperatures across Canada, with northern regions, including YT/NT/NU, experiencing the most significant warming (7,212)). These findings, along with the establishment of the Pan-Territorial Adaptation Partnership, provide strong evidence that these regions are taking collective action and are committed to implementing practical adaptation measures in response to emerging climate-related threats (199).

Among other regions, adaptation plans from Atlantic Canada had the second most recorded sources (22%), followed by the Prairie provinces (19.5%), Central Canada (ON, QC) (14.6%), and the West Coast (7.3%).

Endemic vs. Non-Endemic VBDs in Canada

As expected, the majority of VBDs cited in the peer-reviewed literature were non-endemic, as much of the research (41.2%) focused on North American and global regions outside of Canada. Notably, several studies included research from the southeastern U.S., a region particularly vulnerable to VBDs due to its year-round high temperatures and humid environments, which increase the risk of exposure and have facilitated the establishment of invasive vector species (213). While Canada's current climate does not support vectors for many of these diseases, this finding may also be a concern for the potential introduction or establishment of non-endemic VBDs as conditions change (206).

In contrast, the VBDs highlighted in governmental plans and adaptation strategies primarily reflect those currently endemic to Canada, such as Lyme disease and West Nile virus (214). However, most governmental plans (51.6%) addressed VBDs in broad or general terms, without specifying which diseases their interventions target. It remains unclear whether these governments are taking a comprehensive, proactive approach to monitoring and preparing for VBDs, or if they are inadequately prepared for the emerging threats in their regions. Further examination of these adaptation plans is needed to better understand the level of preparedness across different regions of Canada.

The Representation of Indigenous Communities

A well-represented population within the grey literature were Indigenous communities, appearing in nearly half (38.46%) of the governmental action plans that specified groups beyond vulnerable populations in general. This aligns with Canada's national commitment and efforts to achieve reconciliation with Indigenous Peoples through active involvement and partnership (215). According to the 2021 Census by Statistics Canada, over 1.8 million people in Canada identify as Indigenous making up 5% of the country's total population (216). Indigenous populations, including First Nations, Inuit, and Métis are an important group to consider as climate change poses unique threats to their natural resources, ecosystems, and cultural practices (126). This focus on Indigenous communities in climate change adaptation strategies is consistent with the findings of our study. Indigenous populations are disproportionately affected by environmental changes, as climate change threatens traditional food systems, hunting and fishing practices, and their overall livelihoods (126). Consequently, it is critical for adaptation strategies to prioritize these communities in order to uphold health equity and address the specific vulnerabilities they face. This recognition in the grey literature reflects a growing awareness of the need to include Indigenous perspectives and leadership in developing effective climate adaptation actions.

One Health

Given the need for collaboration in climate change responses, it is important to examine how the
One Health paradigm, an emerging multisectoral and interdisciplinary approach, has been integrated into existing adaptation plans (217). However, only a small proportion of the reviewed plans (9.2%) explicitly mentioned One Health, with 7 out of 8 (87%) of these initiatives being conducted at the national level. This representation at the national level could be attributed to the nature of the documents retrieved, as federal reports tend to focus on broad, overarching strategies, whereas provincial, territorial, and municipal documents typically emphasize specific actions or initiatives. It may also reflect Canada's current position as a "leader in One Health" (217).

The One Health approach is intrinsically linked to the most cited category, *Management, Planning, and Policy* (Category #1), where several provincial and territorial plans (NB, ON, YT) and municipal plans (Toronto, Vancouver, Winnipeg, Quebec City) incorporated multidisciplinary or collaborative action. While these plans may already be applying One Health principles without explicitly stating it, they could benefit from formalizing a One Health strategy to provide more clear structure and coordination for planning and execution.

Additionally, One Health is highly relevant to *Information and Research* (Category #3), which is well represented in adaptation plans across the country (NT, ON, SK, YT, Montreal, Hamilton, Toronto, Ottawa). The approach also underpins the category of *Warning and Observation Systems* (Category #6), particularly in the development, improvement, and expansion of surveillance efforts and networks, where One Health principles are critical to a comprehensive response.

Scope and Limitations

This review takes a comprehensive approach to assess recommended adaptation strategies and governmental actions for addressing the emerging risks by VBDs; however, several limitations should be acknowledged. First, while we grouped adaptation strategies using established frameworks previously used in the literature, data often spanned multiple categories, which our review does not entirely capture. While the reported frequencies offer insight into the relative distribution within each category, they should not be used as standalone metrics for interpretation.

Additionally, the geographic scope was limited to Canada, and municipalities were selected based on population size. Sources were included only if they were available in English, which may have excluded relevant documents if they were only available in French. While our search strategy focused on sources explicitly linking adaptation, VBDs, and climate change, this may potentially overlooked relevant recommendations and actions that did not explicitly mention climate change adaptation. This may explain gaps, particularly in Practice and Behaviour (Category #2), where ongoing activities such as vector surveillance may have been excluded. When interpreting the findings of this review, it is also important to recognize that the absence of identified actions or plans from internal and advanced searches does not necessarily imply that such actions are not being undertaken.

Conclusions

This review provides valuable insights into Canada's response strategies related to climate change and VBDs, highlighting discrepancies between what is being recommended in the literature and the ways in which governments are integrating these recommendations into their climate change action plans.

It is apparent that, coordinated, evidence-based adaptation strategies across all levels of government are essential to effectively address the impacts of VBDs and climate change on health. Our review demonstrates that while many recommended strategies are being incorporated into actions and plans across Canada, there are significant regional variabilities and gaps which remain in certain adaptation areas. To strengthen Canada's response and preparedness, we suggest increased investment in adaptation measures targeting emerging risks of VBDs and broader integration of the One Health approach in subnational and municipal plans. Further research could expand our search to other countries to identify global trends in implementation and investigate the effectiveness of the proposed and implemented adaptation actions.

Supporting Information

S1 Table. Search query for each database used to identify peer-reviewed articles.
(DOCX)

S2 Table. Conducted search for each region used to identify grey literature documents.
(DOCX)

S3 Table. Detailed summary of peer-reviewed literature results of recommended climate change adaptation strategies relating to VBDs.
(DOCX)

S4 Table. Detailed summary of grey literature results of climate change adaptation actions relating to VBDs.
(DOCX)

Author Contributions

Conceptualization: Renée Schryer, Michala Norman, Manisha Kulkarni.
Data Curation: Renée Schryer, Michala Norman.
Formal Analysis: Renée Schryer, Michala Norman.
Funding Acquisition: Manisha Kulkarni.
Investigation: Renée Schryer, Michala Norman.
Methodology: Renée Schryer, Michala Norman.
Project Administration: Manisha Kulkarni.
Resources: Manisha Kulkarni.
Software: Manisha Kulkarni.
Supervision: Manisha Kulkarni.
Validation: Manisha Kulkarni.
Visualization: Renée Schryer, Michala Norman.

Writing- Original Draft Preparation: Renée Schryer, Michala Norman.
Writing- Review & Editing: Manisha Kulkarni.

References

1. Greer A, Ng V, Fisman D. Climate change and infectious diseases in North America: the road ahead. CMAJ Can Med Assoc J. 2008 Mar 11;178(6):715–22.
2. Thomson MC, Stanberry LR. Climate Change and Vectorborne Diseases. Solomon CG, Salas RN, editors. N Engl J Med. 2022 Nov 24;387(21):1969–78.
3. Ogden NH, Maarouf A, Barker IK, Bigras-Poulin M, Lindsay LR, Morshed MG, et al. Climate change and the potential for range expansion of the Lyme disease vector Ixodes scapularis in Canada. Int J Parasitol. 2006 Jan;36(1):63–70.
4. Berry P, Schnitter R. Health of Canadians in a changing climate: advancing our knowledge for action [Internet]. 2022 [cited 2024 May 23] p. 367–443. Available from: https://ostrnrcan-dostrncan.canada.ca/handle/1845/134215
5. IPCC. Sections. In: Climate Change 2023: Synthesis Report [Internet]. 2023. Available from: doi: 10.59327/IPCC/AR6-9789291691647
6. IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Internet]. 2022. Available from: doi:10.1017/9781009325844
7. Bush, E. and Lemmen, D.S. Canada's Changing Climate Report [Internet]. Ottawa, ON; 2019 p. 444. Available from: https://changingclimate.ca/CCCR2019/
8. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. 2018 Oct 2;169(7):467–73.
9. Austin S.E., Ford J.D., Berrang-Ford L., Araos M., Parker S., Fleury M.D. Public health adaptation to climate change in canadian jurisdictions. Int J Environ Res Public Health. 2015;12(1):623–51.
10. Biagini, B., Bierbaum, R., Stults, M., Dobardzic, S., & McNeeley, S. M. A typology of adaptation actions: A global look at climate adaptation actions financed through the Global Environment Facility. 2014 Mar 1;25:97–108.
11. Lugten E, Hariharan N. Strengthening Health Systems for Climate Adaptation and Health Security: Key Considerations for Policy and Programming. Health Secur. 2022 Oct 1;20(5):435–9.
12. Mathieu K, Karmali M. Vector-borne diseases, climate change and healthy urban living: Next steps. Can Commun Rep. 2016;42(10):220–1.
13. Luka N. Emerging challenges of vector-borne diseases for Canadian cities. Can Commun Rep. 2016;42(10):217–8.
14. Mas-Coma S. The importance of emerging and re-emerging zoonotic diseases: recognition, monitoring and control. 2010 Jul 1;277.
15. Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. Managing the health effects of climate change. Lancet Br Ed. 2009;373(9676):1693–733.
16. Zhang Ying, Hansen A, Bi Peng. 1. Climate change and vector-borne viral diseases. In: Viral infections and global change [Internet]. Chichester, UK: John Wiley & Sons; 2014. p. 1–20. Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20143239287&site=ehost-live
17. Barata MM de L. Climate change and urban human health. In: Climate change impacts on urban pests [Internet]. Wallingford, UK: CABI; 2017. p. 165–73. Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20163381102&site=ehost-live

18. Ligsay A, Telle O, Paul R. Challenges to mitigating the urban health burden of mosquito-borne diseases in the face of climate change. Int J Environ Res Public Health [Internet]. 2021;18(9). Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20210242850&site=ehost-live
19. Edelson PJ, Harold R, Ackelsberg J, Duchin JS, Lawrence SJ, Manabe YC, et al. Climate change and the epidemiology of infectious diseases in the United States. Clin Infect Dis. 2022;76(5):950–6.
20. Fielding G, McPherson M, Hansen-Ketchum P, MacDougall D, Beltrami H, Dunn J. Climate change projections and public health systems: building evidence-informed connections. One Health. 2016;2:152–4.
21. Ogden NH, Sockett P, Fleury M. Public Health in Canada and Adaptation to Infectious Disease Risks of Climate Change: Are We Planning or Just Keeping Our Fingers Crossed? In: Adv Glob Change Res [Internet]. Springer International Publishing; 2011. p. 161–75. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84921278554&doi=10.1007%2f978-94-007-0567-8_11&partnerID=40&md5=67def2755b82c9c9718ee7f4e9b70517
22. Ebi KL, Lindgren E, Suk JE, Semenza JC. Adaptation to the infectious disease impacts of climate change. Clim Change. 2013;118(2):355–65.
23. Costello A, Maslin M, Montgomery H, Johnson AM, Ekins P. Global health and climate change: Moving from denial and catastrophic fatalism to positive action. In 2011. p. 1866–82. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-79956078645&doi=10.1098%2frsta.2011.0007&partnerID=40&md5=66cb72d2f1a0b822ed190d898542f559
24. Bedsworth L. California's local health agencies and the state's climate adaptation strategy. Clim Change. 2012;111(1):119–33.
25. Marolla C. Climate health risks in megacities: Sustainable management and strategic planning [Internet]. Clim. Health Risks in Megacities: Sustain. Manag. and Strateg. Plan. CRC Press; 2016. 1 p. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85107529979&doi=10.1201%2f9781315367323&partnerID=40&md5=141551709dcf13bd6fadb985aefe68d0
26. Buse CG. Are climate change adaptation policies a game changer? A case study of perspectives from public health officials in Ontario, Canada. In: Public Health and Welf: Concepts, Methodol, Tools, and Appl [Internet]. IGI Global; 2016. p. 1186–207. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85018568443&doi=10.4018%2f978-1-5225-1674-3.ch055&partnerID=40&md5=8c0d7a306f4c6daf881afa8fe3dde1cb
27. Machalaba C, Romanelli C, Stoett P, Baum SE, Bouley TA, Daszak P, et al. Climate change and health: Transcending silos to find solutions. Ann Glob Health. 2015;81(3):445–58.
28. Levy BS, Patz JA. Climate change. In: Occup and Environ Health [Internet]. Oxford University Press; 2017. p. 605–18. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85052951034&doi=10.1093%2foso%2f9780190662677.003.0032&partnerID=40&md5=aece30cec1380d8d14291aec54f8a7c1
29. Mills JN, Gage KL, Khan AS. Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. Environ Health Perspect. 2010;118(11):1507–14.
30. Deb AK, Kanungo S, Deb M, Nair GB. Impact of climate change on health and strategies for mitigation and adaptation. WHO South-East Asia J Public Health. 2012;1(1):8–19.

31. Galaz V, Osterblom H, Bodin O, Crona B. Global networks and global change-induced tipping points. Int Environ Agreem Polit Law Econ. 2016;16(2):189–221.
32. Dantas-Torres F. Climate change, biodiversity, ticks and tick-borne diseases: the butterfly effect. In Amsterdam, Netherlands: Elsevier Ltd; 2015. p. 452–61. Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20163003439&site=ehost-live
33. Hongoh V, Campagna C, Panic M, Samuel O, Gosselin P, Waaub JP, et al. Assessing Interventions to Manage West Nile Virus Using Multi-Criteria Decision Analysis with Risk Scenarios. PloS One. 2016;11(8):e0160651.
34. Epstein PR. West Nile virus and the climate. J Urban Health Bull N Y Acad Med. 2001;78(2):367–71.
35. Tabachnick WJ. Research Contributing to Improvements in Controlling Florida's Mosquitoes and Mosquito-borne Diseases. Insects. 2016;7(4).
36. Byrd B, Richards SL, Runkle JD, Sugg MM. Vector-borne Diseases and Climate Change: North Carolina's Policy Should Promote Regional Resilience. N C Med J. 2020;81(5):324–30.
37. Rochlin I., Ninivaggi D.V., Hutchinson M.L., Farajollahi A. Climate Change and Range Expansion of the Asian Tiger Mosquito (Aedes albopictus) in Northeastern USA: Implications for Public Health Practitioners. PLoS ONE. 2013;8(4):e60874.
38. Tiffin H.S., Rajotte E.G., Sakamoto J.M., Machtinger E.T. Tick Control in a Connected World: Challenges, Solutions, and Public Policy from a United States Border Perspective. Trop Med Infect Dis. 2022;7(11):388.
39. Errett N.A., Dolan K., Hartwell C., Vickery J., Hess J.J. Climate Change Adaptation Activities and Needs in US State and Territorial Health Agencies. J Public Health Manag Pract JPHMP. 2023;29(3):E115–23.
40. Lesnikowski AC, Ford JD, Berrang-Ford L, Barrera M, Heymann J. How are we adapting to climate change? A global assessment. Mitig Adapt Strateg Glob Change. 2015;20(2):277–93.
41. Barrio MO del, Simard F, Caprara A. Supporting and strengthening research on urban health interventions for the prevention and control of vector-borne and other infectious diseases of poverty: scoping reviews and research gap analysis. Infect Dis Poverty. 2018;7(94):(3 September 2018).
42. Sahay S. Adaptation to health outcomes of climate change and variability at the city level: An empirical decision support tool. Sustain Cities Soc [Internet]. 2019;47. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85063340536&doi=10.1016%2fj.scs.2019.101512&partnerID=40&md5=34a0d99ae97edbd1442545d9c15c160c
43. Gage K.L., Burkot T.R., Eisen R.J., Hayes E.B. Climate and Vectorborne Diseases. Am J Prev Med. 2008;35(5):436–50.
44. Rosenthal J.P., Jessup C.M. Global climate change and health: developing a research agenda for the NIH. Trans Am Clin Climatol Assoc. 2009;120((Rosenthal, Jessup) Division of International Training and Research, Fogarty International Center, National Institutes of Health, Bethesda, Maryland 20892-2220, USA.):129–41.
45. Tajudeen YA, Oladunjoye IO, Mustapha MO, Mustapha ST, Ajide-Bamigboye NT. Tackling the global health threat of arboviruses: an appraisal of the three holistic approaches to health. Health Promot Perspect. 2021;11(4):371–81.
46. Eddy C, Sase E. Part 1: The zika virus threat and prevention challenges: An all-hazards and one health approach to pandemic and global epidemic prevention and mitigation. J Env Health. 2021;84(2):8–18.
47. Braks M, van Ginkel R, Wint W, Sedda L, Sprong H. Climate change and public health policy: translating the science. Int J Environ Res Public Health. 2013;11(1):13–29.

48. Dudley JP, Hoberg EP, Jenkins EJ, Parkinson AJ. Climate Change in the North American Arctic: A One Health Perspective. EcoHealth. 2015;12(4):713–25.
49. Butt M.S., Saleem J., Ishaq M., Bukhari G.M.J., Faryal J. Climate change vulnerability, adaptation assessment, and policy development for occupational health. Avicenna. 2022;2022(2):8.
50. Government of New Brunswick. Transitioning to a Low-Carbon Economy New Brunswick's Climate Change Action Plan Progress Report 2022: Detailed Summary. New Brunswick (NB5); 2022 p. 46.
51. City of Toronto. A Climate of Concern: Climate Change and Health Strategy. 2015 p. 17.
52. City of Vancouver. Climate Change Adaptation Strategy and 2018 update/action plan. Vancouver (VAN1); 2018 p. 58.
53. City of Winnipeg. OurWinnipeg. Winnipeg (WIN1); 2022 p. 108.
54. Government of Canada. Government of Canada adaptation action plan. Canada (CAN1): Government of Canada = Gouvernement du Canada; 2022 p. 108.
55. Environment and Climate Change Canada. Canada's National Adaptation Strategy. Canada (CAN2); 2022.
56. Government of Yukon. Assessing Climate Change risk and resilience in the Yukon. Yukon (YK5.1); 2022.
57. Government of Yukon. Climate Change, Energy and Green Economy What We Heard. Yukon (YK6); 2019 May.
58. Government of Ontario. CLIMATE READY: Ontario's Adaptation Strategy and Action Plan - 2011 - 2014. Ontario (ON1); 2011 p. 124.
59. Government of Canada. Environmental public health and climate change. 2013. Regional Climate Change Dialogues. Available from: https://www.canada.ca/en/public-health/services/health-promotion/environmental-public-health-climate-change/regional-climate-change-dialogues.html
60. Government of Canada. Canada Institutes of Health Research. 2023. Overview of the Lyme Disease Initiative. Available from: https://cihr-irsc.gc.ca/e/51542.html#
61. Government of Canada. Climate Change and Health Vulnerability and Adaptation Assessments: A Knowledge to Action Resource Guide [Internet]. 2021. Available from: https://www.canada.ca/en/health-canada/services/publications/healthy-living/climate-health-adapt-vulnerability-adaptation-assessments-resource-guide.html
62. Lee-Fuller C, Magnan A, Pharand S. Advancing knowledge and increasing capacity to address climate-driven infectious diseases in Canada. Can Commun Dis Rep. 2018 Oct 4;44(10):267–9.
63. Government of Yukon. Our Clean Future A Yukon strategy for climate change, energy and a green economy: Draft strategy. Yukon (YK7.1); 2019 Nov p. 61.
64. Pan-Canadian framework on clean growth and climate change. Gatineau, Quebec: Environment and Climate Change Canada; 2016.
65. City of Ottawa: Planning, Infrastructure and Econmic Development. Climate Change Master Plan. 2020 Dec p. 35.
66. Government of Canada. Climate change: our plan. 2023. Funding opportunities to support adaptation action. Available from: https://www.canada.ca/en/environment-climate-change/services/climate-change/adapting/funding.html
67. Ruiz-Moreno D, Vargas IS, Olson KE, Harrington LC. Modeling Dynamic Introduction of Chikungunya Virus in the United States. Galvani AP, editor. PLoS Negl Trop Dis. 2012 Nov 29;6(11):e1918.
68. Liang SY, Linthicum KJ, Gaydos JC. MSJAMA: Climate change and the monitoring of vector-borne disease. JAMA. 2002;287(17):2286.
69. Soto S.M. Human migration and infectious diseases. Clin Microbiol Infect. 2009;15(SUPPL. 1):26–8.

70. Viennet E., Ritchie S.A., Williams C.R., Faddy H.M., Harley D. Public Health Responses to and Challenges for the Control of Dengue Transmission in High-Income Countries: Four Case Studies. PLoS Negl Trop Dis. 2016;10(9):e0004943.
71. Kraemer M.U., Reiner R.C., Brady O.J., Messina J.P., Gilbert M., Hay S.I., et al. Past and future spread of the arbovirus vectors Aedes aegypti and Ae. albopictus. Am J Trop Med Hyg. 2018;99(4 Supplement):207–8.
72. Wilke A.B.B., Vasquez C., Medina J., Carvajal A., Petrie W., Beier J.C. Community Composition and Year-round Abundance of Vector Species of Mosquitoes make Miami-Dade County, Florida a Receptive Gateway for Arbovirus entry to the United States. Sci Rep. 2019;9(1):8732.
73. Rupasinghe R., Chomel B.B., Martinez-Lopez B. Climate change and zoonoses: A review of the current status, knowledge gaps, and future trends. Acta Trop. 2022;226((Rupasinghe, Martinez-Lopez) Center for Animal Disease Modeling and Surveillance (CADMS), Department of Medicine and Epidemiology, University of California, Davis, CA, United States(Chomel) Department of Population Health and Reproduction, School of Veter):106225.
74. Ryan S.J., Lippi C.A., Villena O.C., Singh A., Murdock C.C., Johnson L.R. Mapping current and future thermal limits to suitability for malaria transmission by the invasive mosquito Anopheles stephensi. Malar J. 2023;22(1):104.
75. Confalonieri U.E., Menezes J.A., de Souza C.M. Climate change and adaptation of the health sector: The case of infectious diseases. Virulence. 2015;6(6):554–7.
76. Ogden N.H. Climate change and vector-borne diseases of public health significance. FEMS Microbiol Lett. 2017;364(19):fnx186.
77. Pataki BA, Garriga J, Eritja R, Palmer JRB, Bartumeus F, Istvan C. Deep learning identification for citizen science surveillance of tiger mosquitoes. Sci Rep [Internet]. 2021;11(2). Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20219843651&site=ehost-live
78. Jansen C.C., Beebe N.W. The dengue vector Aedes aegypti: what comes next. Microbes Infect. 2010;12(4):272–9.
79. Rochlin I., Ninivaggi D.V., Benach J.L. Malaria and Lyme disease - the largest vector-borne US epidemics in the last 100years: success and failure of public health. BMC Public Health. 2019;19(1):804.
80. Kua K.P. A multifactorial strategy for dengue prevention and control: A public health situation analysis. Trop Doct. 2022;52(2):367–71.
81. Watson RT, Patz J, Gubler DJ, Parson EA, Vincent JH. Environmental health implications of global climate change. J Environ Monit JEM. 2005;7(9):834–43.
82. Pereira Cabral B, da Graca Derengowski Fonseca M, Mota FB. Long term prevention and vector control of arboviral diseases: What does the future hold?. Int J Infect Dis IJID Off Publ Int Soc Infect Dis. 2019;89(c3r, 9610933):169–74.
83. Germain G, Simon A, Arsenault J, Baron G, Bouchard C, Chaumont D, et al. Quebec's Multi-Party Observatory on Zoonoses and Adaptation to Climate Change. Can Commun Dis Rep. 2019;45(5):143–8.
84. Government of Canada. Environmental Public Health and Climate Change. Preventative Public Health Systems and Adaptation to a Changing Climate Program. Available from: https://www.canada.ca/en/public-health/services/health-promotion/environmental-public-health-climate-change/preventative-public-health-systems-adaptation-a-changing-climate-program.html
85. Government of Saskatchewan. Upland Game bird management plan 2018-2028. n.d.
86. Tam T. Lyme Disease in Canada: A Federal Framework. Ottawa, ON, CA: Public Health Agency of Canada; 2017.

87. Government of Québec. Québec in Action Greener by 2020. 2012.
88. Patz JA. Climate change and health: new research challenges. In: Managing for healthy ecosystems [Internet]. Boca Raton, USA: CRC Press Inc.; 2003. p. 77–86. Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20033139992&site=ehost-live
89. Gully PR. Pandemics, regional outbreaks, and sudden-onset disasters. Healthc Manage Forum. 2020;33(4):164–9.
90. Gubler D.J., Reiter P., Ebi K.L., Yap W., Nasci R., Patz J.A. Climate variability and change in the United States: Potential impacts on vector- and Rodent-Borne diseases. Environ Health Perspect. 2001;109(SUPPL. 2):223–33.
91. Panic M., Ford J.D. A review of national-level adaptation planning with regards to the risks posed by climate change on infectious diseases in 14 OECD nations. Int J Environ Res Public Health. 2013;10(12):7083–109.
92. Applebaum K.M., Graham J., Gray G.M., LaPuma P., McCormick S.A., Northcross A., et al. An Overview of Occupational Risks From Climate Change. Curr Environ Health Rep. 2016;3(1):13–22.
93. Bouchard C., Dumas A., Baron G., Bowser N., Leighton P.A., Lindsay L.R., et al. Integrated human behavior and tick risk maps to prioritize Lyme disease interventions using a “One Health” approach. Ticks Tick-Borne Dis. 2023;14(2):102083.
94. Donnelly M.A., Marcantonio M., Neteler M., Melton F., Rizzoli A., Barker C.M. Mapping past, present, and future climatic suitability for invasive aedes aegypti and AE. albopictus in the United States: A process-based modeling approach. Am J Trop Med Hyg. 2016;95(5 Supplement 1):253.
95. Martens W.J.M., Slooff R., Jackson E.K. Climate change, human health, and sustainable development. Bull World Health Organ. 1997;75(6):583–8.
96. Ogden N, Gachon P. Climate change and infectious diseases: What can we expect? CCDR. 2019;45(4):76–80.
97. Kinney PL, Matte T, Knowlton K, Madrigano J, Petkova E, Weinberger K, et al. New York City Panel on Climate Change 2015 report. Chapter 5: Public health impacts and resiliency. Ann N Y Acad Sci. 2015;1336:67–88.
98. Adam-Poupart A., Labreche F., Smargiassi A., Duguay P., Busque M.-A., Gagne C., et al. Climate change and occupational health and safety in a temperate climate: Potential impacts and research priorities in Quebec, Canada. Ind Health. 2013;51(1):68–78.
99. Petkova E.P., Ebi K.L., Culp D., Redlener I. Climate change and health on the U.S. Gulf Coast: Public health adaptation is needed to address future risks. Int J Environ Res Public Health. 2015;12(8):9342–56.
100. Weathers MR, Mosher MM, Maibach E. Communicating the public health implications of climate change. In: Research Handb on Communicating Climate Change: Elgar Handbooks in Energy, the Environment and Climate Change [Internet]. Edward Elgar Publishing Ltd.; 2020. p. 259–71. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85133672222&doi=10.4337%2f9781789900408.00038&partnerID=40&md5=7b12925a71295f5a7bf16591e33ef4bd
101. Akerlof K, Debono R, Berry P, Leiserowitz A, Roser-Renouf C, Clarke KL, et al. Public perceptions of climate change as a human health risk: surveys of the United States, Canada and Malta. Int J Environ Res Public Health. 2010;7(6):2559–606.
102. Kipp A, Cunsolo A, Vodden K, King N, Manners S, Harper SL. At-a-glance - Climate change impacts on health and wellbeing in rural and remote regions across Canada: a synthesis of the literature. Health Promot Chronic Dis Prev Can Res Policy Pract. 2019;39(4):122–6.

103. Ebi K. Climate change and health risks: Assessing and responding to them through “adaptive management.” Health Aff (Millwood). 2011;30(5):924–30.
104. Hueffer K., Parkinson A.J., Gerlach R., Berner J. Zoonotic infections in Alaska: disease prevalence, potential impact of climate change and recommended actions for earlier disease detection, research, prevention and control. Int J Circumpolar Health. 2013;72((Hueffer, Parkinson, Gerlach, Berner) Department of Biology and Wildlife, University of Alaska Fairbanks, Fairbanks, AK, USA).
105. Christaki E. New technologies in predicting, preventing and controlling emerging infectious diseases. Virulence. 2015;6(6):558–65.
106. Burrows H., Talbot B., McKay R., Slatculescu A., Logan J., Thickstun C., et al. A multi-year assessment of blacklegged tick (Ixodes scapularis) population establishment and Lyme disease risk areas in Ottawa, Canada, 2017-2019. PLoS ONE. 2021;16(2 February):e0246484.
107. Tong S., Ebi K. Preventing and mitigating health risks of climate change. Environ Res. 2019;174((Tong) Shanghai Children’s Medical Centre, Shanghai Jiao Tong University School of Medicine, Shanghai, China(Tong) School of Public Health, Institute of Environment and Population Health, Anhui Medical University, Hefei, China(Tong) School of Public Healt):9–13.
108. Lashley F.R. Emerging infectious disease: Vulnerabilities, contributing factors and approaches. Expert Rev Anti Infect Ther. 2004;2(2):299–316.
109. Higa Y. Dengue vectors and their spatial distribution. Trop Med Health. 2011;39(4 (Supplement)):17–27.
110. Wong GKL, Jim CY. Do vegetated rooftops attract more mosquitoes? Monitoring disease vector abundance on urban green roofs. Sci Total Environ. 2016;573(uj0, 0330500):222–32.
111. Carvalho B.M., Rangel E.F., Vale M.M. Evaluation of the impacts of climate change on disease vectors through ecological niche modelling. Bull Entomol Res. 2017;107(4):419–30.
112. Lohmus M., Balbus J. Making green infrastructure healthier infrastructure. Infect Ecol Epidemiol. 2015;5(1):30082.
113. Stephen C, Duncan C. Can wildlife surveillance contribute to public health preparedness for climate change? A Canadian perspective. Clim Change. 2017;141(2):259–71.
114. Nelder MP, Wijayasri S, Russell CB, Johnson KO, Marchand-Austin A, Cronin K, et al. The continued rise of Lyme disease in Ontario, Canada: 2017. Can Commun Dis Rep Releve Mal Transm Au Can. 2018;44(10):231–6.
115. Lieske DJ, Lloyd VK. Combining public participatory surveillance and occupancy modelling to predict the distributional response of Ixodes scapularis to climate change. Ticks Tick-Borne Dis. 2018;9(3):695–706.
116. Guo E, Agusto FB. Baptism of fire: modeling the effects of prescribed fire on Lyme disease. Can J Infect Dis Med Microbiol [Internet]. 2022;2022(5300887). Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20220240831&site=ehost-live
117. New Brunswick climate change action plan 2014-2020. Fredericton [New Brunswick]: Province of New Brunswick; 2014.
118. Ministry of Environment and Climate Change Strategy. Preliminary strategic climate risk assessment for British Columbia [Internet]. British Columbia (BC2): Koninklijke Brill NV; 2019 Jul [cited 2023 Oct 1] p. 429. Available from: https://primarysources.brillonline.com/browse/climate-change-and-law-collection/preliminary-strategic-climate-risk-assessment-for-british-columbia;cccc012820190128484

119. New Brunswick Department of Environment. Atlantic Region Adaptation Science Activities. New Brunswick (NB3); 2010.
120. Northwest Territories: Environment and natural resources. NWT CLIMATE CHANGE IMPACTS AND ADAPTATION REPORT 2008. NWT (NWT2); 2008.
121. Government of the Northwest Territories. NWT Climate Change Action Plan: Annual Report 2019/20. NWT (NWT1.3); 2020 p. 120.
122. Ormond P, Eng P. GRIDS background study: Hamilton's vulnerability to climate change. Hamilton (HAM6); 2004 p. 41.
123. City of Montréal - Service de l'environnement. Climate Change Adaptation Plan for the Montreal Urban Agglomeration 2015-2020. 2015.
124. The City of Kitchener. Kitchener, Changing for GOOD.
125. Government of the Northwest Territories, Department of Education, Culture and Employment. Building a Path for Northern Science Government of the Northwest Territories' Science Agenda. NWT (NWT6); 2009 p. 36.
126. Government of the Northwest Territories. 2030 NWT CLIMATE CHANGE STRATEGIC FRAMEWORK. NWT (NWT1); 2019 p. 108.
127. Government of the Northwest Territories. 2030 NWT CLIMATE CHANGE STRATEGIC FRAMEWORK 2019-2023 Action Plan. NWT (NWT1.2); 2019 p. 60.
128. City of Hamilton. City of Hamilton: Climate change impact adaptation plan. Hamilton (HAM1); 2022 p. 86.
129. Government of Canada. Environmental Public Health and Climate Change. 2013. Pilot Infectious Disease Impact and Response Systems (PIDIRS) Program. Available from: https://www.canada.ca/en/public-health/services/health-promotion/environmental-public-health-climate-change/pilot-infectious-disease-impact-response-systems-pidirs-program.html
130. Government of Yukon. Our Clean Future 2020 Annual Report. 2021.
131. City of Toronto. Climate Change and Health Strategy: 2016 Update. Toronto (TO3); 2016.
132. Todoric D, Vrbova L, Mitri ME, Gasmi S, Stewart A, Connors S, Zheng H, Bourgeois AC, Drebot M, Paré J, Zimmer M. An overview of the National West Nile Virus Surveillance System in Canada: A One Health approach. 2022; Available from: https://www.canada.ca/en/public-health/services/reports-publications/canada-communicable-disease-report-ccdr/monthly-issue/2022-48/issue-5-may-2022/west-nile-virus-surveillance-system-one-health-approach.html
133. Groshong L, Stanis SW, Morgan M. Perceptions of climate change-related health threats among state park visitors. Recreat Parks Tour Public Health. 2021;5:37–64.
134. Zawarus P. GREEN INFRASTRUCTURE FOR MOSQUITO CONTROL. In: Architectural Factors for Infection and Disease Control [Internet]. Taylor and Francis; 2022. p. 109–25. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85142555026&doi=10.4324%2f9781003214502-9&partnerID=40&md5=7fd1117fe2e96967ffb7bd79153a5c5f
135. Leal Filho W, Ternova L, Fayyaz MM, Abubakar IR, Kovaleva M, Donkor FK, et al. An analysis of climate change and health hazards: results from an international study. Int J Clim Change Strateg Manage. 2022;14(4):375–98.
136. Beniston M. Climatic change: possible impacts on human health. Swiss Med Wkly. 2002;132(25–26):332–7.
137. Cameron L, Rocque R, Penner K, Mauro I. Evidence-based communication on climate change and health: Testing videos, text, and maps on climate change and Lyme disease in Manitoba, Canada. PloS One. 2021;16(6):e0252952.
138. Patz J.A., McGeehin M.A., Bernard S.M., Ebi K.L., Epstein P.R., Grambsch A., et al. The potential health impacts of climate variability and change for the United States: Executive

summary of the report of the health sector of the U.S. national assessment. Environ Health Perspect. 2000;108(4):367–76.

139. Liu Q., Chen J., Zhou X.-N. Preparedness for Chagas disease spreading worldwide. Infect Dis Poverty. 2020;9(1):44.
140. Mcmichael A.J., Sari Kovats R. Climate change and climate variability: Adaptations to reduce adverse health impacts. Environ Monit Assess. 2000;61(1):49–64.
141. McMichael AJ, Lindgren E. Climate change: present and future risks to health, and necessary responses. J Intern Med. 2011;270(5):401–13.
142. Semenza JC, Ebi KL. Climate change impact on migration, travel, travel destinations and the tourism industry. J Travel Med. 2019;26(5).
143. Memari M, Domney A, Tee CJ, Stathopoulos AG, Chakraborti C. Barriers to Timely Diagnosis and Treatment of Vector-Borne Diseases in a Changing Climate: A Case Report. Public Health Rep Wash DC 1974. 2023;138(3):406–9.
144. Parkinson A.J., Butler J.C. Potential impacts of climate change on infectious diseases in the Arctic. Int J Circumpolar Health. 2005;64(5):478–86.
145. Rainham D.G.C. Ecological complexity and West Nile Virus: Perspective on improving public health response. Can J Public Health. 2005;96(1):37–40.
146. Dumic I., Severnini E. “ticking Bomb”: The impact of climate change on the incidence of lyme disease. Can J Infect Dis Med Microbiol. 2018;2018((Dumic) Mayo Clinic College of Medicine and Science, Rochester, MN, United States(Dumic) Division of Hospital Medicine, Mayo Clinic Health System, Eau Claire, WI, United States(Severnini) Carnegie Mellon University, Heinz College, 4800 Forbes Ave., Pittsb):5719081.
147. Kulkarni M.A., Berrang-Ford L., Buck P.A., Drebot M.A., Lindsay L.R., Ogden N.H. Major emerging vector-borne zoonotic diseases of public health importance in Canada. Emerg Microbes Infect. 2015;4((Kulkarni) School of Epidemiology, Public Health and Preventive Medicine, University of Ottawa, Ottawa, ON K1H 8M5, Canada(Berrang-Ford) Department of Geography, McGill University, Montreal, QC H3A 0B9, Canada(Buck) Zoonoses Division, Centre for Food-born):e33.
148. McMichael A.J. Extreme weather events and infectious disease outbreaks. Virulence. 2015;6(6):543–7.
149. Bouchard C, Dibernardo A, Koffi J, Wood H, Leighton PA, Lindsay LR. Increased risk of tick-borne diseases with climate and environmental changes. Can Commun Dis Rep. 2019;45(4):81–9.
150. Government of Saskatchewan. Saskatchewan’s Climate Resilience Measurement Framework. Saskatchewan (SK12); 2017 p. 8.
151. Chartered Professional Accountants of Canada. Adaptation Case Study #6: City of Montreal. 2016 p. 8.
152. Government of Yukon. Our Clean Future A Yukon strategy for climate change, energy and a green economy. Yukon (YK7.2); 2020 p. 72.
153. Government of British Columbia. Draft principles to guide the provinceo of BC’s work on climate preparedness and adaptation. BC (BC3); 2021 p. 12.
154. Gl B. Built environment and health.
155. Dvorak A.C., Solo-Gabriele H.M., Galletti A., Benzecry B., Malone H., Boguszewski V., et al. Possible impacts of sea level rise on disease transmission and potential adaptation strategies, a review. J Environ Manage. 2018;217((Dvorak, Solo-Gabriele, Galletti, Benzecry, Malone) Dept. of Civil, Architectural and Environmental Engineering, University of Miami, Coral Gables, FL, United States(Boguszewski) Public Health Analyst, Key West, FL, United States(Bird) CH2M, Tampa, FL, Un):951–68.
156. Howard C, Huston P. The health effects of climate change: Know the risks and become part of the solutions. CCDR. 2019;45(5):114–8.

157. Degallier N, Favier C, Menkes C, Lengaigne M, Ramalho WM, Souza R, et al. Toward an early warning system for dengue prevention: modeling climate impact on dengue transmission. Clim Change. 2010;98(3/4):581–92.
158. Ng V, Rees EE, Lindsay LR, Drebot MA, Brownstone T, Sadeghieh T, et al. Could exotic mosquito-borne diseases emerge in Canada with climate change? Can Commun Dis Rep. 2019;45(4):98–107.
159. Ogden LE. Climate change, pathogens, and people: the challenges of monitoring a moving target. BioScience. 2018;68(10):733–9.
160. Levy BS, Patz JA. Climate Change, Human Rights, and Social Justice. Ann Glob Health. 2015;81(3):310–22.
161. Anonymous. How Does a Changing Climate Impact the Health of Workers? Part 5: Vectorborne Disease. J Occup Environ Med. 2019;61(2):e66–8.
162. Ebi K.L., Burton I. Identifying practical adaptation options: an approach to address climate change-related health risks. Environ Sci Policy. 2008;11(4):359–69.
163. Manore C.A., Davis J.K., Christofferson R.C., Wesson D.M., Hyman J.M., Mores C.N. Spatial analysis and evaluation of 2014 predictions for a West Nile virus early warning system. Am J Trop Med Hyg. 2014;91(5 SUPPL. 1):255.
164. Morin C.W., Semenza J.C., Trtanj J.M., Glass G.E., Boyer C., Ebi K.L. Unexplored Opportunities: Use of Climate- and Weather-Driven Early Warning Systems to Reduce the Burden of Infectious Diseases. Curr Environ Health Rep. 2018;5(4):430–8.
165. Lewis J, Boudreau CR, Patterson JW, Bradet-Legris J, Lloyd VK. Citizen Science and Community Engagement in Tick Surveillance-A Canadian Case Study. Healthc Basel Switz. 2018;6(1).
166. Geier M, Rose A, Grunewald J, Jones O. New mosquito traps improve the monitoring of disease vectors. Int Pest Control. 2006;48(3):124–6.
167. Sagurova I, Ludwig A, Ogden NH, Pelcat Y, Dueymes G, Gachon P. Predicted northward expansion of the geographic range of the tick vector Amblyomma americanum in North America under future climate conditions. Environ Health Perspect. 2019;127(10):EHP5668.
168. Desjardins M, Hohl A, Delmelle E, Casas I. Identifying and Visualizing Space-Time Clusters of Vector-Borne Diseases. In: Geospatial Technology for Hum Well-Being and Health [Internet]. Springer International Publishing; 2022. p. 203–17. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85158947192&doi=10.1007%2f978-3-030-71377-5_11&partnerID=40&md5=935c782cfd39e03930236d544bc4e9e4
169. Otranto D., Wall R. New strategies for the control of arthropod vectors of disease in dogs and cats. Med Vet Entomol. 2008;22(4):291–302.
170. Canyon D.V., Speare R., Burkle F.M. Forecasted Impact of Climate Change on Infectious Disease and Health Security in Hawaii by 2050. Disaster Med Public Health Prep. 2016;10(6):797–804.
171. Tambo E., Khayeka-Wandabwa C., Olalubi O.A., Adedeji A.A., Ngogang J.Y., Khater E.I. Addressing knowledge gaps in molecular, sero-surveillance and monitoring approaches on Zika epidemics and other arbovirus co-infections: A structured review. Parasite Epidemiol Control. 2017;2(2):50–60.
172. Dannenberg AL, Frumkin H, Hess JJ, Ebi KL. Managed retreat as a strategy for climate change adaptation in small communities: public health implications. Clim Change. 2019;153(1–2):1–14.
173. Allen S.E., Jardine C.M., Hooper-McGrevy K., Ambagala A., Bosco-Lauth A.M., Kunkel M.R., et al. Serologic evidence of arthropod-borne virus infections in wild and captive ruminants in Ontario, Canada. Am J Trop Med Hyg. 2020;103(5):2100–7.
174. Grobusch L.C., Grobusch M.P. A hot topic at the environment-health nexus: investigating the impact of climate change on infectious diseases. Int J Infect Dis. 2022;116((Grobusch) Erasmus Mundus Joint Masters Degree in Environmental Sciences, Policy and

Management, University of Lund, Sweden and Central European University, Vienna, Lund, Austria(Grobusch) Center of Tropical Medicine and Travel Medicine, Department of Inf):7–9.

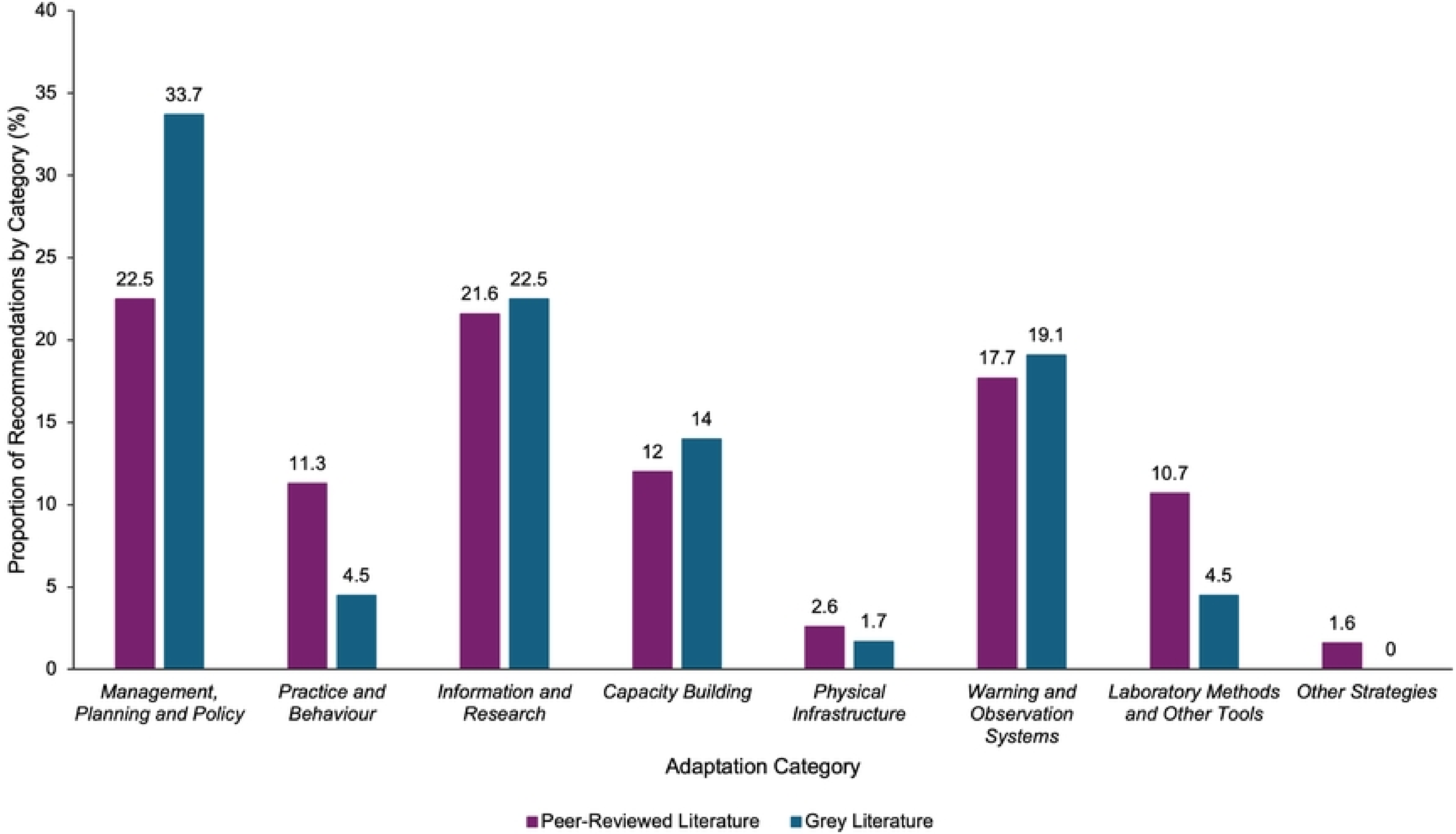
175. Humphreys J.M., Pelzel-Mccluskey A.M., Cohnstaedt L.W., McGregor B.L., Hanley K.A., Hudson A.R., et al. Integrating spatiotemporal epidemiology, eco-phylogenetics, and distributional ecology to assess west nile disease risk in horses. Viruses. 2021;13(9):1811.
176. Porter WT, Barrand ZA, Wachara J, Davall K, Mihaljevic JR, Pearson T, et al. Predicting the current and future distribution of the western black-legged tick, Ixodes pacificus, across the western US using citizen science collections. PLoS ONE [Internet]. 2021;16(1). Available from: https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20210249976&site=ehost-live
177. Sadilek A., Hswen Y., Bavadekar S., Shekel T., Brownstein J.S., Gabrilovich E. Lymelight: forecasting Lyme disease risk using web search data. Npj Digit Med. 2020;3(1):16.
178. Bacon EA, Kopsco H, Gronemeyer P, Mateus-Pinilla N, Smith RL. Effects of climate on the variation in abundance of three tick species in Illinois. J Med Entomol. 2021;59(2):700–9.
179. Myers S.S., Gaffikin L., Golden C.D., Ostfeld R.S., Redford K.H., Ricketts T.H., et al. Human health impacts of ecosystem alteration. Proc Natl Acad Sci U S A. 2013;110(47):18753–60.
180. Gibb R., Franklinos L.H.V., Redding D.W., Jones K.E. Ecosystem perspectives are needed to manage zoonotic risks in a changing climate. The BMJ. 2020;371((Gibb, Franklinos, Redding, Jones) Centre for Biodiversity and Environment Research, Division of Biosciences, University College London, London, United Kingdom(Franklinos) Institute for Global Health, University College London, London, United Kingdom(Redd):m3389.
181. Glidden C.K., Murran A.R., Silva R.A., Castellanos A.A., Han B.A., Mordecai E.A. Phylogenetic and biogeographical traits predict unrecognized hosts of zoonotic leishmaniasis. PLoS Negl Trop Dis. 2023;17(5):e0010879.
182. Liu AY, Trtanj JM, Lipp EK, Balbus JM. Toward an Integrated System of Climate Change and Human Health Indicators: A Conceptual Framework. Clim Change. 2021;166(3–4).
183. Luber G., Prudent N. Climate change and human health. Trans Am Clin Climatol Assoc. 2009;120((Luber, Prudent) Global Climate Change, Division of Environmental Hazards and Health Effects, National Center for Environmental Health, CDC, 4770 Buford Highway, NE, MS F-57, Atlanta, Georgia 30341, USA.):113–7.
184. Schærström A. Disease Diffusion. In: Int Encycl of Hum Geogr [Internet]. Elsevier Inc.; 2009. p. 222–33. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85069581288&doi=10.1016%2fB978-008044910-4.00330-8&partnerID=40&md5=1caeaab4417f45c828b9949608acc126
185. Kotchi SO, Bouchard C, Brazeau S, Ogden NH. Earth observation-informed risk maps of the lyme disease vector Ixodes scapularis in central and eastern Canada. Remote Sens [Internet]. 2021;13(3). Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85103880835&doi=10.3390%2frs13030524&partnerID=40&md5=c533552c946cd071866917dbf4d1bd99
186. Rees EE, Ng V, Gachon P, Mawudeku A, McKenney D, Pedlar J, et al. Risk assessment strategies for early detection and prediction of infectious disease outbreaks associated with climate change. Can Commun Dis Rep Releve Mal Transm Au Can. 2019;45(5):119–26.
187. Kotchi SO, Bouchard C, Ludwig A, Rees EE, Brazeau S. Using Earth observation images to inform risk assessment and mapping of climate change-related infectious diseases. Can Commun Dis Rep Releve Mal Transm Au Can. 2019;45(5):133–42.

188. Case E, Shragai T, Harrington L, Ren Y, Morreale S, Erickson D. Evaluation of unmanned aerial vehicles and neural networks for integrated mosquito management of Aedes albopictus (Diptera: Culicidae). J Med Entomol. 2020;57(5):1588–95.
189. Olson S.H., Benedum C.M., Mekaru S.R., Preston N.D., Mazet J.A.K., Joly D.O., et al. Drivers of emerging infectious disease events as a framework for digital detection. Emerg Infect Dis. 2015;21(8):1285–92.
190. Government of Canada. West Nile virus and other mosquito-borne diseases surveillance report: Annual edition 2019 [Internet]. 2023. Available from: https://www.canada.ca/en/public-health/services/publications/diseases-conditions/mosquito-borne-diseases-surveillance-annual-report-2019.html
191. Government of Saskatchewan. Climate Resilience in Saskatchewan 2019 Report. Saskatchewan (SK4); 2019 p. 38.
192. Government of Saskatchewan. Climate Resilience in Saskatchewan 2020 Report. Saskatchewan (SK3); 2020 p. 39.
193. Government of Saskatchewan. Climate Resilience in Saskatchewan 2021 Report. Saskatchewan (SK2); 2021 p. 48.
194. Government of Saskatchewan. Prairie Resilience: A Made-in-Saskatchewan Climate Change Strategy. Saskatchewan (SK1); 2015 p. 13.
195. Municipal Affairs and Environment Climate Change Branch (Government of Newfoundland and Laborador). The Way Forward on Climate Change in Newfoundland and Labrador. Newfoundland and Laborador (NL1); 2019 p. 52.
196. Ducrocq J, Forest-Bérard K, Ouhoummane N, Sidi EL, Ludwig A, Irace-Cima A. A meteorological-based forecasting model for predicting minimal infection rates in Culex pipiens-restuans complex using Québec's West Nile virus integrated surveillance system. 2022; Available from: https://www.canada.ca/en/public-health/services/reports-publications/canada-communicable-disease-report-ccdr/monthly-issue/2022-48/issue-5-may-2022/meteorological-tool-predict-west-nile-virus-infection.html
197. Dr. Vera Etches, Medical Officer of Health. Ottawa Public Health Work on Climate Change [Internet]. 2019. Available from: https://www.ottawapublichealth.ca/en/public-health-topics/resources/Documents/OTTAWA-PUBLIC-HEALTH-WORK-ON-CLIMATE-CHANGE.pdf
198. Northwest R, Hershfield M. Yukon 'State of Play': Analysis of Climate Change Impacts and Adaptation. Yukon (YK1); 2017 p. 74.
199. Governments of Nunavut, Yukon, Northwest Territories. Pan-Territorial Adaptation Strategy: Moving forward on climate change adaptation in Canada's north. Pan-Territorial (REG1); 2011 Apr p. 32.
200. Jd G, Young I, Harding S, Mascarenhas M, Waddell L. A scoping review of Lyme disease research relevant to public health. CCDR. 2018;44(10):243–56.
201. Naze F., Le Roux K., Schuffenecker I., Zeller H., Staikowsky F., Grivard P., et al. Simultaneous detection and quantitation of Chikungunya, Dengue and West Nile viruses by multiplex RT-PCR assays and Dengue virus typing using High Resolution Melting. J Virol Methods. 2009;162(1–2):1–7.
202. Maynard N.G., Conway G.A. A view from above: use of satellite imagery to enhance our understanding of potential impacts of climate change on human health in the Arctic. Alaska Med. 2007;49(3):78–85.
203. Malone J.B., Bergquist R., Martins M., Luvall J.C. Use of geospatial surveillance and response systems for vector-borne diseases in the elimination phase. Trop Med Infect Dis. 2019;4(1):tropicalmed4010015.
204. Valois P, Bouchard D, Aenishaenslin C, Talbot D, Bouchard C, Briand S, et al. Development and validation of a behavioral index for adaptation to Lyme disease. BMC Public Health [Internet]. 2020;20(1435). Available from:

https://search.ebscohost.com/login.aspx?direct=true&db=lhh&AN=20203461578&site=ehost-live

205. Guillot C., Bouchard C., Aenishaenslin C., Berthiaume P., Milord F., Leighton P.A. Criteria for selecting sentinel unit locations in a surveillance system for vector-borne disease: A decision tool. Front Public Health. 2022;10((Guillot, Bouchard, Aenishaenslin, Berthiaume, Leighton) Groupe de recherche en epidemiologie des zoonoses et sante publique (GREZOSP), Faculte de medecine veterinaire, Universite de Montreal, QC, Canada(Guillot, Milord) Faculte de medecine et des science):1003949.
206. Otten A., Fazil A., Chemeris A., Breadner P., Ng V. Prioritization of vector-borne diseases in Canada under current climate and projected climate change. Microb Risk Anal. 2020;14((Otten, Fazil, Ng) National Microbiology Laboratory, Public Health Agency of Canada, Guelph, Ontario, Canada(Chemeris) Department of Food, Agriculture and Resource Economics, University of Guelph, Guelph, Ontario, Canada(Breadner) Faculty of Science, Univ):100089.
207. Lee W.L., Gu X., Armas F., Leifels M., Wu F., Chandra F., et al. Monitoring human arboviral diseases through wastewater surveillance: Challenges, progress and future opportunities. Water Res. 2022;223((Lee, Gu, Armas, Chandra, Chen, Ooi, Alm) Antimicrobial Resistance Interdisciplinary Research Group, Singapore-MIT Alliance for Research and Technology, Singapore 138602, Singapore(Lee, Gu, Armas, Chandra, Chen, Ooi, Alm, Thompson) Campus for Research Exc):118904.
208. Agarwal A., Sarma D.K., Chaurasia D., Maan H.S. Novel molecular approaches to combat vectors and vector-borne viruses: Special focus on RNA interference (RNAi) mechanisms. Acta Trop. 2022;233((Agarwal, Chaurasia, Maan) State Virology Laboratory, Department of Microbiology, Gandhi Medical College, Madhya Pradesh, Bhopal 462001, India(Sarma) ICMR-National Institute for Research in Environmental Health, Madhya Pradesh, Bhopal 462030, India):106539.
209. Ogden NH, Robbin Lindsay L, Drebot MA. Zoonoses. In: Climate Change and Animal Health [Internet]. CRC Press; 2022. p. 141–55. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85143940460&doi=10.1201%2f9781003149774-7&partnerID=40&md5=68c5008764d3e67a3bb550d568ef0a0f
210. Cole BL, Rosario ID, Hendricks A, Eisenman DP. Advancing Health Equity in Community-Based Climate Action: From Concept to Practice. 2023;
211. Bátiz LF, Illanes SE, Romero R, Barrera MDV, Mattar CNZ, Choolani MA, et al. Climate change and preterm birth: A narrative review. Env Adv [Internet]. 2022;10. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85142531552&doi=10.1016%2fj.envadv.2022.100316&partnerID=40&md5=badb1b593d75aae9459fb00a237cbb48
212. Rantanen M, Karpechko AY, Lipponen A, Nordling K, Hyvärinen O, Ruosteenoja K, et al. The Arctic has warmed nearly four times faster than the globe since 1979. Commun Earth Environ. 2022 Aug 11;3(1):1–10.
213. Dye-Braumuller KC, Gordon JR, Johnson D, Morrissey J, McCoy K, Dinglasan RR, et al. Needs Assessment of Southeastern United States Vector Control Agencies: Capacity Improvement Is Greatly Needed to Prevent the Next Vector-Borne Disease Outbreak. Trop Med Infect Dis. 2022 May 13;7(5):73.
214. Lindsay L. Present state of common vector-borne diseases in Canada. Can Commun Dis Rep. 2016 Oct 6;42(10):200–1.
215. Canada G of CCIR and NA. Reconciliation [Internet]. 2014 [cited 2024 Nov 24]. Available from: https://www.rcaanc-cirnac.gc.ca/eng/1400782178444/1529183710887

216. Canada; G of CCIR and NA. Indigenous peoples and communities [Internet]. 2009 [cited 2024 Oct 7]. Available from: https://www.rcaanc-cirnac.gc.ca/eng/1100100013785/1529102490303
217. Johnson N, Phipps LP, Hansford KM, Folly AJ, Fooks AR, Medlock JM, Mansfield KL. One Health approach to tick and tick-borne disease surveillance in the United Kingdom. 2022;



40
35
30
25
20
15
10
5
0
Proportion of Recommendations by Category (%)
22.5
33.7
11.3
4.5
21.6
22.5
12
14
2.6
1.7
17.7
19.1
10.7
4.5
1.6
0
Management, Planning and Policy
Practice and Behaviour
Information and Research
Capacity Building
Physical Infrastructure
Warning and Observation Systems
Laboratory Methods and Other Tools
Other Strategies
Adaptation Category
Peer-Reviewed Literature
Grey Literature

Figure 3

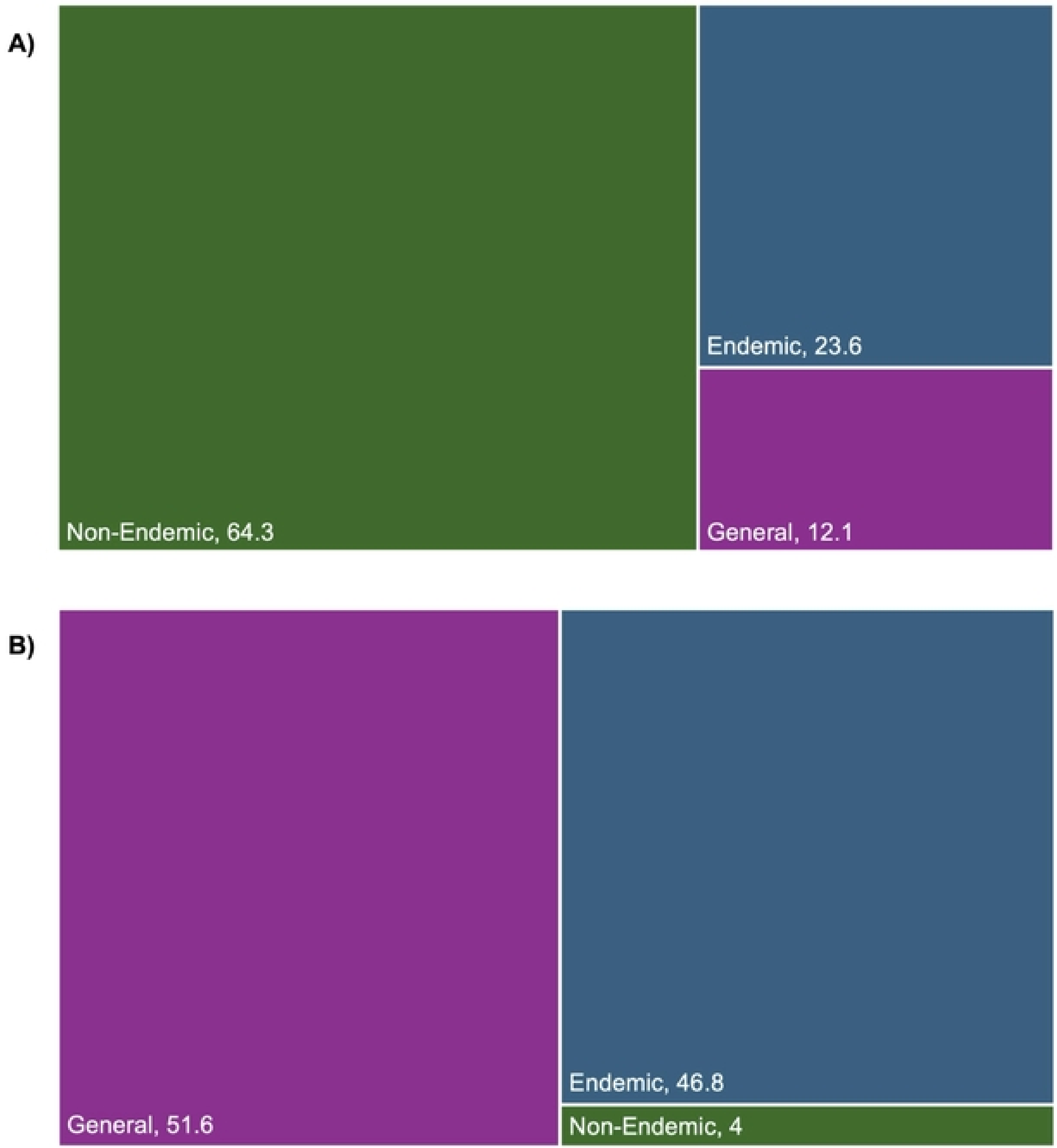

A)
Endemic, 23.6
Non-Endemic, 64.3
General, 12.1
B)
Endemic, 46.8
General, 51.6
Non-Endemic, 4

Figure 4

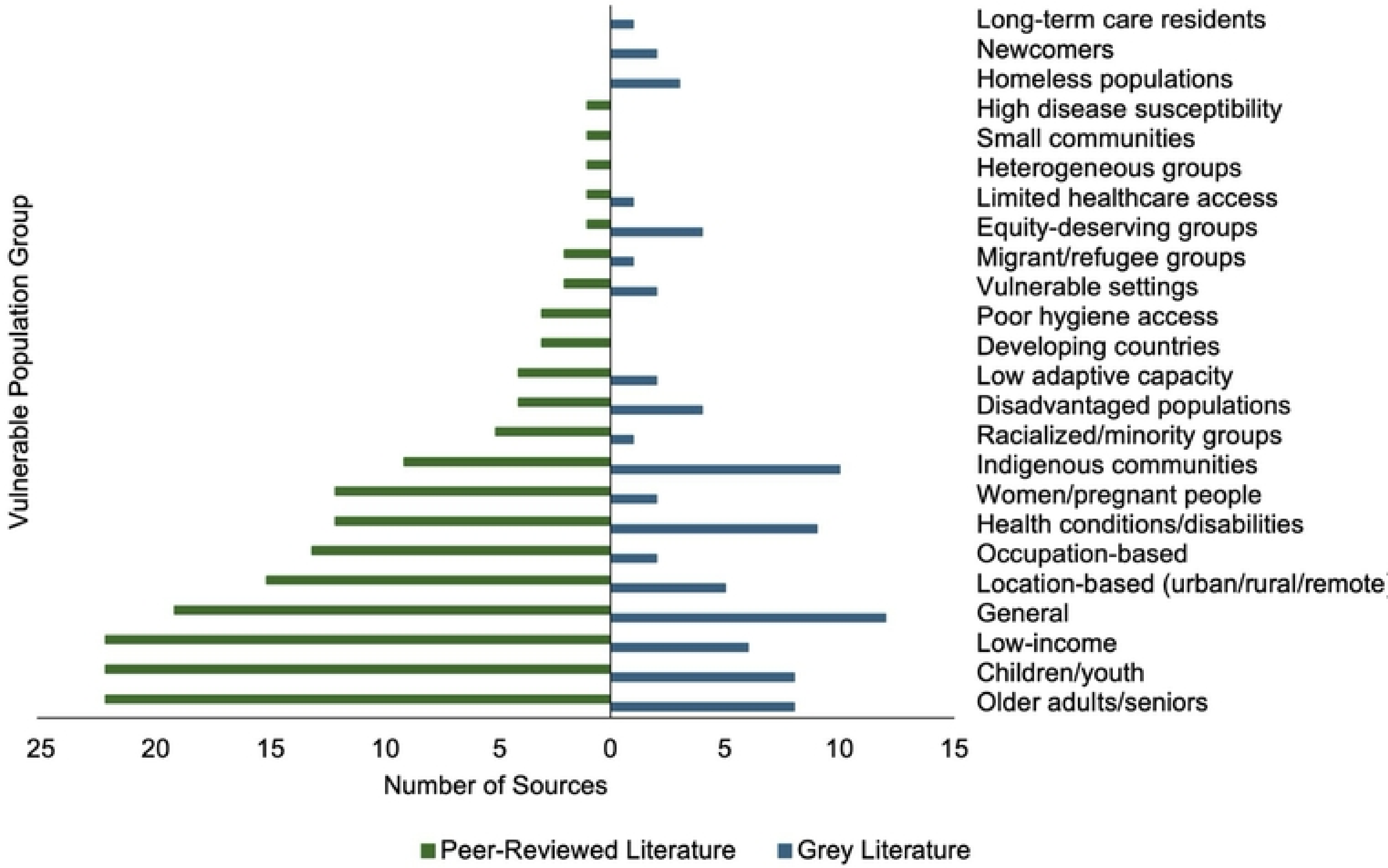

Vulnerable Population Group
Long-term care residents
Newcomers
Homeless populations
High disease susceptibility
Small communities
Heterogeneous groups
Limited healthcare access
Equity-deserving groups
Migrant/refugee groups
Vulnerable settings
Poor hygiene access
Developing countries
Low adaptive capacity
Disadvantaged populations
Racialized/minority groups
Indigenous communities
Women/pregnant people
Health conditions/disabilities
Occupation-based
Location-based (urban/rural/remote)
General
Low-income
Children/youth
Older adults/seniors
25 20 15 10 5 0 5 10 15
Number of Sources
Peer-Reviewed Literature
Grey Literature

Figure 5

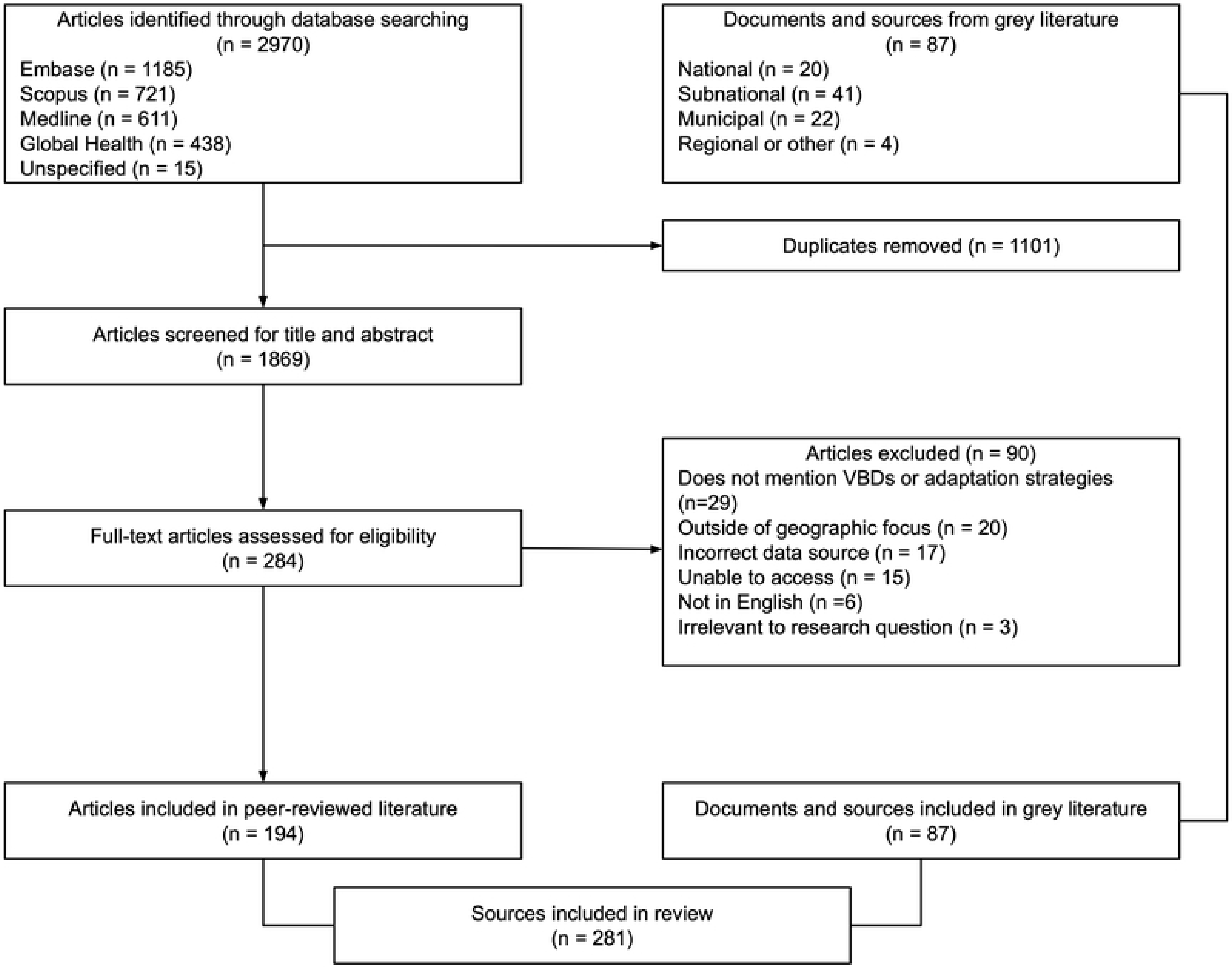

Articles identified through database searching
(n = 2970)
Embase (n = 1185)
Scopus (n = 721)
Medline (n = 611)
Global Health (n = 438)
Unspecified (n = 15)
Documents and sources from grey literature
(n = 87)
National (n = 20)
Subnational (n = 41)
Municipal (n = 22)
Regional or other (n = 4)
Duplicates removed (n = 1101)
Articles screened for title and abstract
(n = 1869)
Articles excluded (n = 90)
Does not mention VBDs or adaptation strategies
(n=29)
Outside of geographic focus (n = 20)
Incorrect data source (n = 17)
Unable to access (n = 15)
Not in English (n =6)
Irrelevant to research question (n = 3)
Full-text articles assessed for eligibility
(n = 284)
Articles included in peer-reviewed literature
(n = 194)
Documents and sources included in grey literature
(n = 87)
Sources included in review
(n = 281)

Figure 1

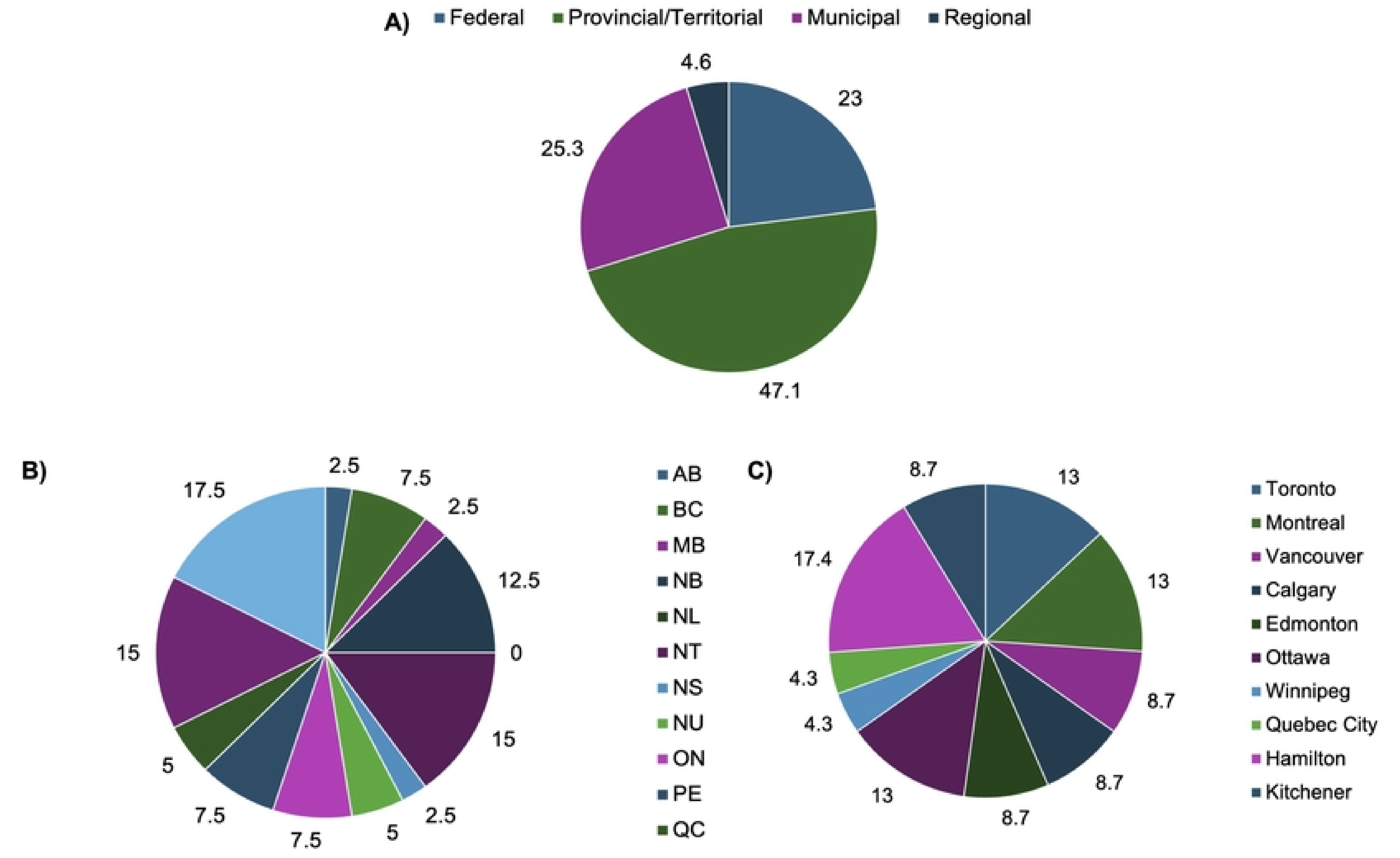

A)
Federal
Provincial/Territorial
Municipal
Regional
4.6
23
25.3
47.1
B)
2.5
7.5
2.5
17.5
12.5
15
0
15
5
7.5
7.5
5
2.5
AB
BC
MB
NB
NL
NT
NS
NU
ON
PE
QC
C)
8.7
13
17.4
13
4.3
8.7
4.3
13
8.7
8.7
Toronto
Montreal
Vancouver
Calgary
Edmonton
Ottawa
Winnipeg
Quebec City
Hamilton
Kitchener

Figure 2