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ORIGINAL PAPER

Assessing Canada's disaster baselines and projections under the Sendai Framework for Disaster Risk Reduction: a modeling tool to track progress

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Abstract

Under the United Nations (UN) Sendai Framework for Disaster Risk Reduction (2015–2030), 187 countries including Canada committed to increasing disaster resilience and reducing disaster losses by 2030. In order to track these commitments, the UN developed methodological guidance to establish baselines and assess progress across seven global targets for disaster risk reduction. This article describes research that employs the UN methodology to create baselines and targets for Canada, and extends the UN methodology further by developing a statistical modeling software application to project current trends to the year 2030. Based on the results, Canada would need to prevent 88 hazard events from becoming disasters; keep the disaster fatality rate near zero; avoid 4700 disaster-related injuries; prevent 556,000 people from being evacuated; avoid $92 billion in disaster losses; and protect significant sources of critical infrastructure from disruption. Three key limitations were identified in the research: First, there was a lack of consistent Canadian data across impact categories and over time; second, the historical record of disasters, particularly hydrometeorological disasters, may not be an adequate proxy for the future; and third there were also acute prediction limitations in the projection model which could not account for very frequent small-scale and very infrequent catastrophic-scale disaster events. Though the model projections suggest Canada may face a significant challenge in the years ahead, with a recently announced $180 billion infrastructure investment plan, there is an opportunity for Canada to better manage disaster risks, by not just building back better, but also building smart to start.

Keywords Sendai Framework · DRR · Canada

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1 Introduction

At the Third United Nations World Conference on Disaster Risk Reduction, in March 2015, 187 countries, including Canada, adopted the *Sendai Framework for Disaster Risk Reduction (2015–2030) (SFDRR)*. By signing this agreement, signatory nations committed to increasing disaster resilience and substantially reducing disaster losses, in terms of human, social, economic, and environmental impacts. The 15-year non-binding SFDRR builds on a litany of predecessor frameworks, all of which have pursued similar objectives. The catalogue of previous agreements includes: the *International Decade for Natural Disaster Reduction (1990–1999)*; the *Yokohama Strategy and Plan of Action for a Safer World (1994)*; and the *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*. Unfortunately, despite each successive framework, disaster impacts in Canada, and globally, have continued to mount (Briceño 2015; UNISDR 2015a, b, c; de la Poterie and Baudoin 2015).

In an attempt to ensure more transparency and accountability for disaster losses during the 15 years of the SFDRR, signatory countries agreed to high-level global priorities for action and, for the first time, established tangible global targets for disaster risk reduction (DRR) (see Table 1). The setting of these targets brings the SFDRR in line with the other comparable "post-2015 agenda" international agreements the *Sustainable Development Goals* and the *Paris Agreement on Climate Change* (UNISDR 2015a). At the request of signatory countries, the United Nations developed a standard methodology, lexicon, and indicators to measure the global targets for DRR at the national level. This collection of technical notes and guidance for monitoring and reporting on the progress in achieving global targets for DRR was approved by the United Nations General Assembly in 2017 (UNISDR 2017).

This study seeks to explore disaster impact trends in Canada by applying the United Nations DRR standard methodology to measure Canadian baselines for the SFDRR targets and then applies a statistical forecasting methodology to estimate the changes in SFDRR target indicators during the SFDRR monitoring decade (2020–2030). The pairing of these two measures enables the development of an estimate of the unmitigated residual risk for Canada at the end of the SFDRR period. To accomplish this modeling, we developed an open-source statistical modeling software application in the "R Project for Statistical Computing" language environment. The results of the modeling are presented for each target, where possible, with a brief discussion on specific data source issues for targets that could not be modeled. While the software application is currently calibrated to Canadian datasets, it could easily be applied by international researchers moving forward to better target risk reduction efforts in any country. As such, this study represents one of the first applications in the literature of the United Nations methodology for measuring DRR as well as describing a new tool for signatory countries to project their probable disaster impacts during the SFDRR period.

1.1 Context

From 2005–2015, international disaster impacts increased significantly, leading to average annual losses of $314 billion (USD); 700 thousand deaths; 1.4 million injuries; 23 million people being made homeless; and 1.5 billion people being impacted by disasters (UNISDR 2015a, b). People and assets continued on their 40-year migration toward urban

Table 1 SFDRR global targets and qualitative data readiness assessment

Global targets	# Of indicators	Data availability	Data sources
(0) Substantially reduce total disaster events by 2030, aiming to lower average per disaster frequency rate in the decade 2020–2030 compared to the period 2005–2015	1 Indicator	Good (1/1)	CDD (PSC 2017a)
(A) Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005–2015	1 Compound indicator; 2 sub-indicators	Good (2/3)	CDD (PSC 2017a)
(B) Substantially reduce the number of affected people globally by 2030, aiming to lower average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015	1 Compound indicator; 4 sub-indicators	Moderate (3/5)	CDD (PSC 2017a); NRCAN Wildfire Evacuation
(C) Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030	1 Compound indicator; 4 sub-indicators	Good (4/5)	CDD (PSC 2017a), Insurance Bureau of Canada, Catastrophic Loss Indices, provincial agricultural insurers[a]
(D) Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030	2 Compound indicator; 6 sub-indicators	Poor (2/8)	Canadian Electricity Association
(E) Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020	2 Indicators	N/A qualitative only	N/A
(F) Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this framework by 2030	8 Indicators	N/A qualitative only	N/A

Table 1 (continued)

Global targets	# Of indicators	Data availability	Data sources
(G) Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030	1 Indicator, 1 compound indicator; 4 sub-indicators	N/A qualitative only	N/A

[a]Manitoba Agricultural Services Corporation Insurance (MB), AgriService (BC), AgriCorp (ON), Agriculture Financial Services Corporation (AB), AgriInsurance (NL), Agricultural Insurance Corporation (PE), La Financière agricole du Québec (QC) and Agriculture, Aquaculture and Fisheries (NB)

centers located in flood-prone river basins (increasing by 114%), cyclone-exposed shorelines (increasing by 192%), and active seismic areas (now 50% of large cities) (UNISDR 2011). The rapid urbanization in hazard zones has led to an increase in the risk exposure of economic assets and earning potential around the globe (UNISDR 2011, 2012, 2015b). In addition to the increased exposure, unsustainable land use, ecosystem degradation, weak governance, and increases in poverty and inequality further contributed to growing disaster vulnerabilities globally (UNISDR 2015a, b).

The trend of increasing disaster risk is exacerbated in the face of anthropogenic climate change, which is contributing to increases in the frequency, intensity, and variability of weather- and climate-related hazards (IPCC 2012, 2014). That said, while climate change has the potential to deliver unprecedented extreme events, many large-scale disasters to date fall within the parameters of historical hazard event variability (IPCC 2012). As such, global DRR efforts appear insufficient to address the extremes of natural variability that have yet to occur, and let alone those made possible through climate change (IPCC 2012, 2014; UNISDR 2015a, b).

Noticeably, as disaster losses continued to grow, countries reported to the United Nations increases in their disaster management capacity over the decade of 2005–2015 (IPCC 2012; Briceño 2015; UNISDR 2015a). Countries described how stakeholder engagement through global, regional, and national platforms for DRR led to the development of more coordinated DRR policy instruments (UNISDR 2015a). Simultaneously, the body of knowledge on disaster risk and vulnerability had also advanced. Specifically, there has been a growing recognition of the need for applied transdisciplinary science, which not only moves beyond traditional scientific disciplines and stakeholders but also integrates traditional and local knowledge into DRR (Ismail-Zadeh et al. 2017). These more targeted research efforts led to the conceptual shift from disaster management to disaster risk management in the SFDRR. This continues the progression toward more proactive actions in advance of disasters, building back better after events, and recognizing the sociopolitical, health, and power dynamics at the root of disaster vulnerability (Ismail-Zadeh et al. 2017; Aitsi-Selmi et al. 2015; UNISDR 2015b).

1.2 Canada

Canada is the second largest country in the world geographically and one of the most sparsely populated nations, with 35,000,000 people spread across 8,965,000 km^2, and it has a population density of 3.9 persons/km^2 (Statistics Canada 2017). Immigrants make up 28.6% of the Canadian population, and Canada's indigenous peoples add another 4.8%, further contributing to the cultural richness of Canadian society (Statistics Canada 2017). The natural environment in Canada is equally diverse covering fifteen discrete ecozones, including: one of the world's longest coastlines, at 244,000 km; temperate rain forests in the south to arctic tundra in the north; and mountain ranges, prairie grassland, and boreal ecosystems spreading from west to east across the country (Lindsay 2009). The Canadian economy is currently ranked 18th globally with a gross domestic product of $1.8 billion USD, driven predominantly by its natural resources, manufacturing, and skilled labor markets (International Monetary Fund 2018). Politically, Canada is a federal parliamentary democracy and, as a former British colony, a constitutional monarchy. Sub-nationally, Canada is divided into ten provinces and three territories, which vary significantly in their size, population, and economy.

Disaster risk reduction in Canada is broadly pursued under the title of "Emergency Management" and is a shared responsibility among federal, provincial, and territorial governments, through an interpretation of the Chapter 6, *sections 91 and 92* of the Canadian Constitution known as the peace, order, and good governance clause. Through subsequent laws, and by convention, the federal government is generally concerned with issues that cross provincial boundaries (e.g., military, postal service, navigation, shipping, etc.), while provinces address issues within their borders (e.g., health care, education, municipal institutions, etc.). The main legislative guidance on the subject of DRR is provided in the federal *Emergency Management Act (2007)*, which outlines the four interconnected activity areas of emergency management: prevention/mitigation, preparedness, response, and recovery (Government of Canada 2007).

2 Methods

As previously mentioned, the UN General Assembly has endorsed a methodological guidance report titled the *Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Related to Disaster Risk Reduction* (UNGA 2017). Through the endorsement process, signatory nations requested the UNISDR to provide technical guidance on developing minimum standards for DRR terminology and indicators and develop methodologies for the measurement and processing of statistical data related to national-level targets under the SFDRR. In December 2017, the UNISDR published a collection of technical notes for guidance on monitoring and reporting on progress in achieving the global targets (UNISDR 2017).

At its core, the UNISDR methodology implements a quantitative national-level approach to measure direct disaster impacts (targets A–D) and the advancement of policies to support disaster risk management (targets E–G). The theoretical foundation of this methodology builds on the international scientific advances of the last decade; a comprehensive discussion on these methodological foundations is contained in the UNISDR methodological guidance documents (UNISDR 2017).

The UNISDR methodology serves as the core foundation of indicator data collection and analysis in this article. Some deviations from the UNISDR guidance were necessary based on data availability; however, these minor deviations are indicated where they occur. A significant addition to the UNISDR methodology was the development and application of a new domestic target and modeling category for disaster frequency labeled "Target 0," designed to leverage the significant historical disaster data available in Canada.

2.1 Data sources and adjustments

The Canadian Disaster Database (CDD) was a significant source of data for our analysis. The CDD includes an interactive geospatial map and database, which contains detailed disaster information on more than 1000 natural, technological, and conflict events since 1900 A.D. To be officially tracked, through the CDD, disaster events must meet more specific criteria, namely: 10 or more people killed; 100 or more people affected/injured/infected/evacuated or homeless; an appeal for national/international assistance; historical significance; and/or, significant damage/interruption of normal processes such that the community affected cannot recover on its own (PSC 2017a). This definition of a disaster event is adopted in this article for consistency sake, except where noted otherwise. The reporting of the disaster type, or causal hazard, for CDD entry appears to be at the discretion of the CDD staff, and where multiple hazards are associated with a single event (e.g., earthquake and tsunami) the hazard which caused the most direct impacts to Canadians is listed first, though multiple hazards are also sometimes assigned to a single CDD entry. Given the natural hazards focus of the SFDRR, the disaster events addressed in this paper are limited to the ones initiated by natural hazards, filtering out technological and conflict-induced events. The CDD provided datasets for disaster frequency, fatalities, injuries, evacuations, and federal Disaster Financial Assistance Arrangements (DFAAs) costs, all of which can be disaggregated by hazard and by geography (provincial level).

The DFAA is the primary means by which the Government of Canada aids provinces and territories deal with the financial burden of disaster response and recovery activities (PBO 2016; PSC 2017b). This cost-sharing program determines federal assistance based on *per capita* disaster losses, up to a maximum of 90% of eligible disaster response and recovery costs and overall losses (PSC 2017b). Federal direct disaster loss data, which account for uninsurable public and personal losses, are drawn from official DFAA data, which were made public through the CDD in 2016. However, these data represent only the federal portion of losses and do not capture disaster events that do not meet federal cost-sharing thresholds.

Private sector aggregate insurance losses were derived from two industry sources: Insurance Bureau of Canada (IBC) and the Catastrophe Indices and Quantification Inc. (CatIQ). These databases aggregate insurable loss figures from participating Canadian insurers for catastrophic events, defined as those exceeding $25 million (CAD) in single-event losses. Although tremendously useful resources, in order to maintain competitive advantage among Canadian insurers, the data in IBC and CatIQ are aggregated to the event and annual levels, so further disaggregation of these datasets was not possible. The inability to disaggregate events by jurisdiction means that we were unable to collate the data for individual events, and instead could only derive economic analysis for the entire country annually. This does not negatively impact the overall measurement of the UNISDR target, but it does reduce our ability to derive regionally specific analyses and recommendations.

The overall availability of data for Canada varied across the seven SFDRR targets and the newly developed Target 0. This variability is outlined in Table 1, which presents the seven SFDRR targets, plus our target 0, tracks the UNISDR indicator data availability for Canada, and assesses the qualitative readiness of data for monitoring as: poor, less than 33% of indicator datasets; moderate, 33–66% of indicator datasets; good, 66% or indicator datasets; and not applicable (N/A), if no datasets were available.

The available datasets were scrubbed, dollar values were normalized to 2016 dollars using the Bank of Canada's inflation calculator, and all values were collated to annual time-series data points. The lengths of the time-series datasets were dictated by the availability of consistent data within each of the UNISDR target categories. From the perspective of UNISDR reporting, the historical data which predated 2005 were not relevant to the reporting methodology; however, it was indicative for the second portion of our analysis which involved predicting the statistical trends which could then be compared against the UNISDR baselines in order to better understand the scale of the gulf between *status quo* trends and Canada's national-level SFDRR targets.

2.2 Data analysis

For the statistical forecasts, a variety of modeling approaches were considered, but given the limitations of time-series data and our inability to convincingly correlate annual disaster impacts with other relevant drivers, such as the IPCCs Global Climate Models, over the SFDRR reporting period, a Box–Jenkins approach to fit autoregressive integrated moving average (ARIMA) models was applied to the historical datasets from the CDD and other sources. This approach is based on previous Canadian efforts at forecasting conditional hazard probabilities from the CDD in Dore (2003). These forecasts introduced the most impactful assumption into our research, that trends would follow curvilinear progressions over the next decade. The potential issues with this approach are discussed at length in the limitations section of this article. Despite the potential critique of this type of rudimentary modeling, we feel that this approach provides a transparent process for forecasting trends that can be replicated in other countries with limited resources and datasets, and reduces the introduction of complex modeling assumptions, which require further transformations to our already imperfect datasets.

The analyses were conducted using the R Project for statistical computing language environment. The R program was selected because of its ability to provide a wide variety of statistical linear and nonlinear modeling tests, analyses, and graphing functions. Additionally, because R is an open language environment all codes, programming, and functions can be accessed or altered by anyone, which facilitates regular reporting using consistent calculations and enables the integration of new data inputs over time.

As such, we developed a menu-based program in R for Canadian SFDRR reporting with pre-programmed functions built into the program to ensure that, despite updates and changes in datasets, identical statistical approaches can be applied to reporting for the duration of the SFDRR period. Initially, the "hybridTS" package was used, but in many cases the results were questionable due to the large error bars on the forecasted mean (at both 80% and 95% confidence intervals). This is often the result of inadequate data points in the original dataset. Since a flat or linear sloping projection/forecast was desired, the time-series forecast did not succeed in that regard. The time-series model would often produce a polynomial forecast curve with peaks and troughs (similar to a sine wave), which is likely the result of the model picking up a cyclic trend, especially with the DFAA losses time series. We used the built-in statistical functionality in R, fitting models of the following form:

> Disaster ~ intercept + B1 * year + B2 * year^2, where B1 describes a linear increase in the consequences of disaster with year, while B2 can describe an accelerating increase or decrease with year.

In the case of CDD data, there were some years with no events and/or no figures or multiple provinces under certain categories. Except where noted, these occurrences were coded as "0" in the data, but assigned a code of "no hazard" or "no province," which gets rolled into the "other" category in the resulting figures. When creating charts where certain provinces accounted for a small percentage of the data (e.g., 1–5%) these provinces were aggregated into the category "misc." in order to avoid confusion with the "other" category. These data include forecasts for the 2017–2019 periods (because the decade does not have complete data), and from the full datasets, projections for 2020–2030. In some cases where data were missing, reasonable estimates were produced using the "imputeTS" package in R that uses various statistical methods such as weighted moving average (simple, linear, or exponential) to fill in missing data.

Since DFAA losses data covers the period from 1970 to 2016, the 2017 to 2020 values were filled in using estimates from the Government of Canada's Parliamentary Budget Officer (2016). The commercial loss data covers the period from 1983 to 2016. The data from 1983 to 2013 are from IBC, and the 2014–2016 data are from CatIQ. Since the plot of DFAA versus private sector losses starts at 1980, the years 1980–1983 and 2017–2020 were filled in using weighted moving average methods to match the period of the DFAA losses prior to performing the forecasting for 2021–2030. Agricultural losses data cover the period of 2005–2015, but the weighted moving average methods produced values that were unrealistically high due to the short period of the data. Therefore, the missing data were filled in using a polynomial regression and the forecasted values from 1980 to 2004 and an extrapolated forecast for 2016–2020.

In order to have consistent evacuation data for wildfires, a comparison was made between the Natural Resources Canada Wildland Fire Evacuation database and the CDD wildfire evacuations numbers for the corresponding years. It was found that there were 92,419 wildfire evacuees missing from the CDD. The annual totals from both databases were compared and the differences were calculated. New simulated wildfire events were then added for inconsistent years. As a result, the new number of evacuees from wildfires has accounted for this difference and the figures are now consistent with the Wildland Fire Evacuation database.

To be consistent with the SFDRR indicators, we initially used rates per 100,000 rather than totals for fatalities, injuries, evacuations, and electrical outages. The rate per 100,000 for each year was calculated using the following formula:

$$\text{Rate} = \text{Number of outages} \times (100{,}000/\text{total population}).$$

With the exception of a few years, most fatality figures were very close to zero. Both the 1936 heat wave and the 1950 Red River Floods produced high values but were retained because neither negatively impacts the results. The 1918 epidemic value was removed as a catastrophic-scale biological disaster which significantly skewed our forecasts. A discussion on how catastrophic-scale events are unrepresented in modeling approach is presented in the limitations section.

3 Results

Given the salience of the findings to Canada's capacity for addressing the goals outlined in the SFDRR, the findings have been organized by each of the specific targets, including Target 0, developed specifically for the Canadian context. For each of the disaster impact targets (0 and A–D), a dedicated sub-results section contains the original target, a description of the specific data included in the analysis, a figure summarizing the findings, and a summary of findings disaggregated by hazard and geography (where relevant).

3.1 Target 0: Substantially reduce total disaster events by 2030, aiming to lower average disaster frequency rate in the decade 2020–2030 compared to the period 2005–2015

For disaster frequency, the CDD lists 854 events between 1900 and 2016 ($N=117$). The Canadian baseline, 2005–2015 annual mean disaster frequency rate ($N=11$), is 187 disasters reaching CDD thresholds, an average of 17 disasters per year, represented by the purple horizontal line in Fig. 1a. Given current projections, over the SFDRR measurement period (2020–2030), this number is set to increase along the fitted polynomial trend line ($R^2=0.73$, $p=0.000$) to 26 disasters per year by the end of 2030, or 264 disasters over the SFDRR measurement period, represented by the blue curve in Fig. 1a. This means that in

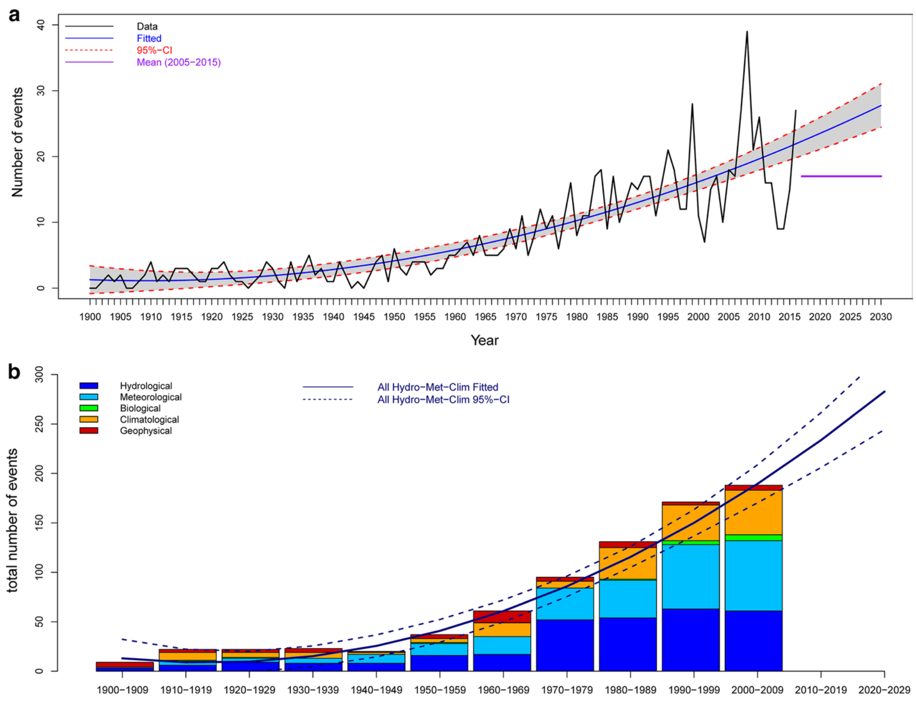


Fig. 1 **a** Frequency of Natural Disasters in Canada (1900–2030). **b** Natural hazard frequency by decade and hazard subgroup in Canada (1900–2030)

order to meet its national target for disaster frequency, Canada would need to prevent 88 disasters from reaching CDD thresholds between 2020 and 2030. It is also evident that disasters under the hydrological, meteorological, and climatological categories are increasing more rapidly compared to geophysical and biological categories (Fig. 1b).

The disaggregation of historical disaster frequency data from 1900 to present ($N=117$) can only be accomplished for geography (Fig. 2) and by hazard (Fig. 3). Geographically, Canada's four most populous provinces account for the majority of disaster events with Ontario, British Columbia, Quebec, and Alberta cumulatively accounting for 86.2% of the Canadian population and 60.9% of disaster events. Multi-provincial events are also a significant category at 9.7%. In terms of disaggregation by hazard, the hazard that accounts for the most disasters in Canada is flooding, at 35.4%. Severe thunderstorms (14.4%) and wildfires (14.7%) round out the top three hazards, cumulatively accounting for 64.5% of all disaster in Canada.

3.2 Target A: Substantially reduce global disaster mortality by 2030, aiming to lower average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005–2015

Disaster fatality figures draw on the same CDD historical data as Target 0 ($N=117$). In the baseline period (2005–2015), Canada experienced 485 disaster-related fatalities, an annual rate of 0.0085 disaster-related fatalities per 100,000 ($N=11$) (Fig. 4). If current trends continue, Canada's disaster fatality rate appears to be on a downward trend ($R^2=0.025$,

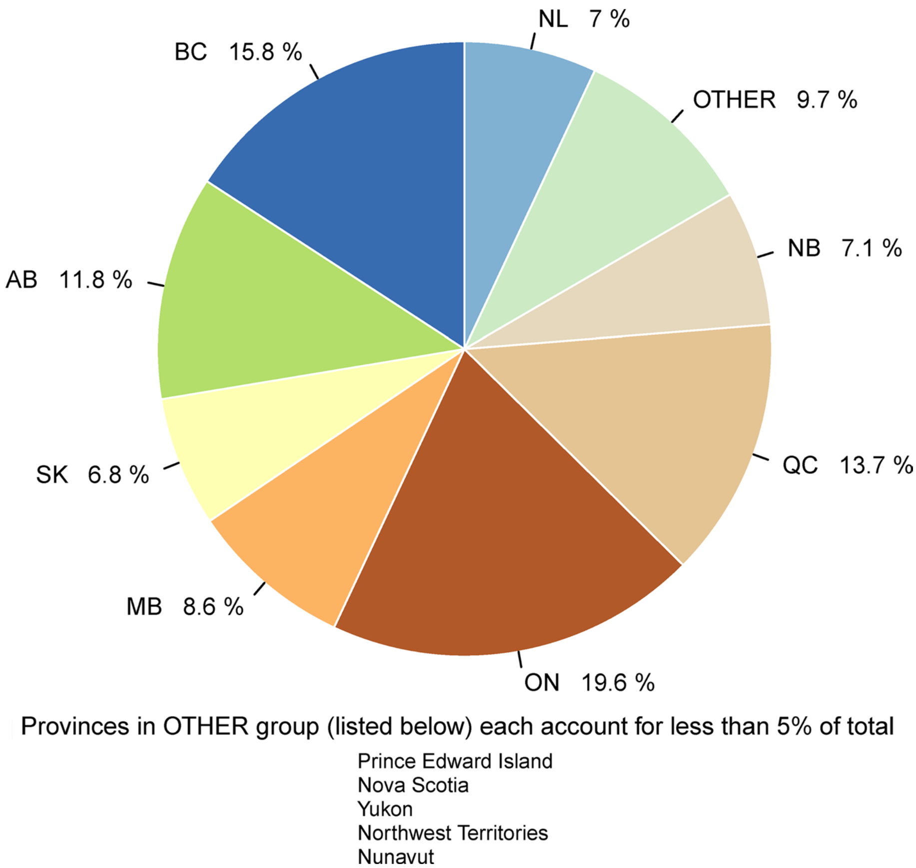


Fig. 2 Natural disaster frequency by province (1900–2016)

$p = 0.41$); however, given the high p value in this model, the prediction does not meet the threshold for a clear statistical trend.

The cumulative disaster mortality figures ($N = 117$) from the CDD can be disaggregated both for geography (Fig. 5) and by hazard (Fig. 6). Given the relatively low numbers of disaster-related deaths in Canada's history, the figures that follow are represented as absolute values, rather than rates per 100,000. Disaster-related fatalities in the provinces of Ontario (21.7%), British Columbia (18.7%), Newfoundland (16.6%), and Quebec (6.4%) account for the majority (63.4%) of reported fatalities. By hazard type, heat events (35.8%), severe thunderstorms (15.7%), winter storms (14.4%), landslide (8.6%), and wildfires (8.0%) account for the majority of historical disaster fatalities in Canada.

3.3 Target B: Substantially reduce the number of affected people globally by 2030, aiming to lower average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015

In the baseline decade, 2005–2015 ($N = 11$), Canada experienced 9423 disaster-related injuries, a rate of 0.016 injuries per 100,000 annually (Fig. 7) and 277,913 evacuations,

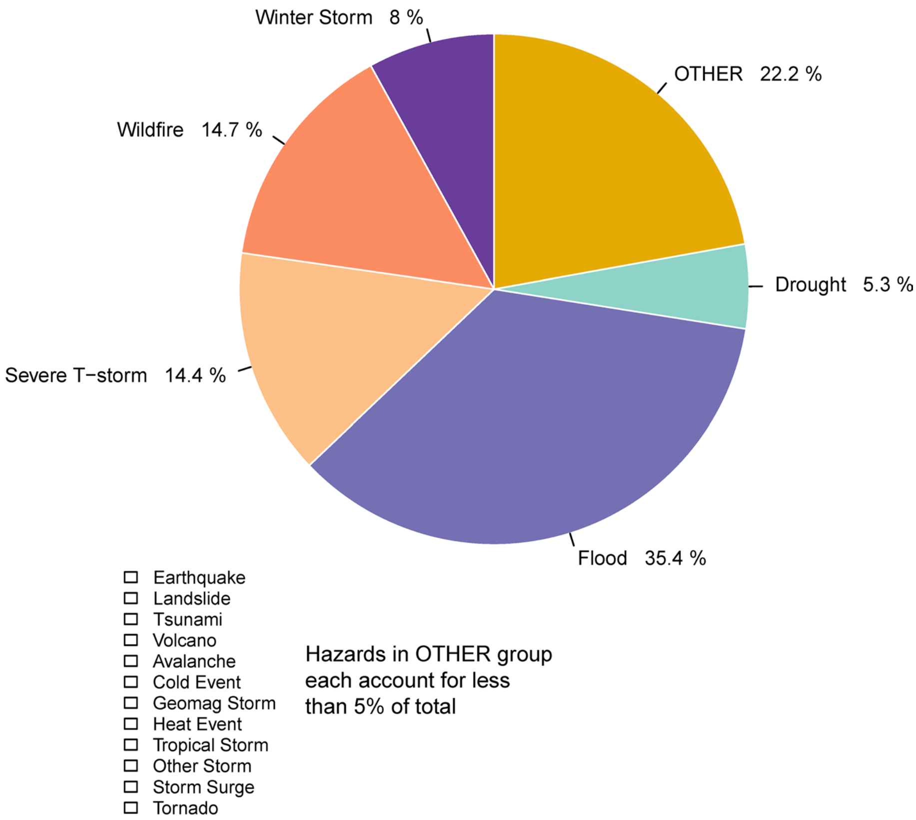


Fig. 3 Natural disaster frequency by hazard for all provinces (1900–2016)

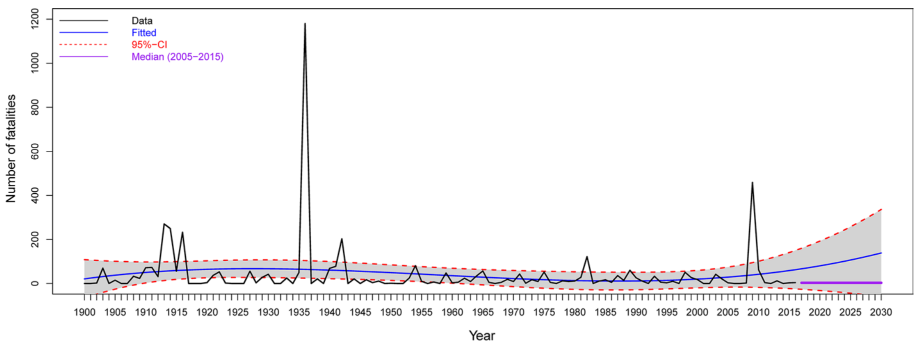


Fig. 4 Natural disaster fatalities in Canada (1900–2030)

a rate of 44 people per 100,000 (Fig. 8). If historical trends continue, Canada's disaster injury rate will fall to 0.008 ($R^2=0.077$, $p=0.029$), meaning that Canada should expect roughly 4712 disaster-related injuries, in absolute terms, between 2020 and 2030. According to the model, Canada's evacuation rate will continue to increase to 128 people per 100,000 by 2030 ($R^2=0.35$, $p<0.001$), or 833,729 disaster-related evacuations during the

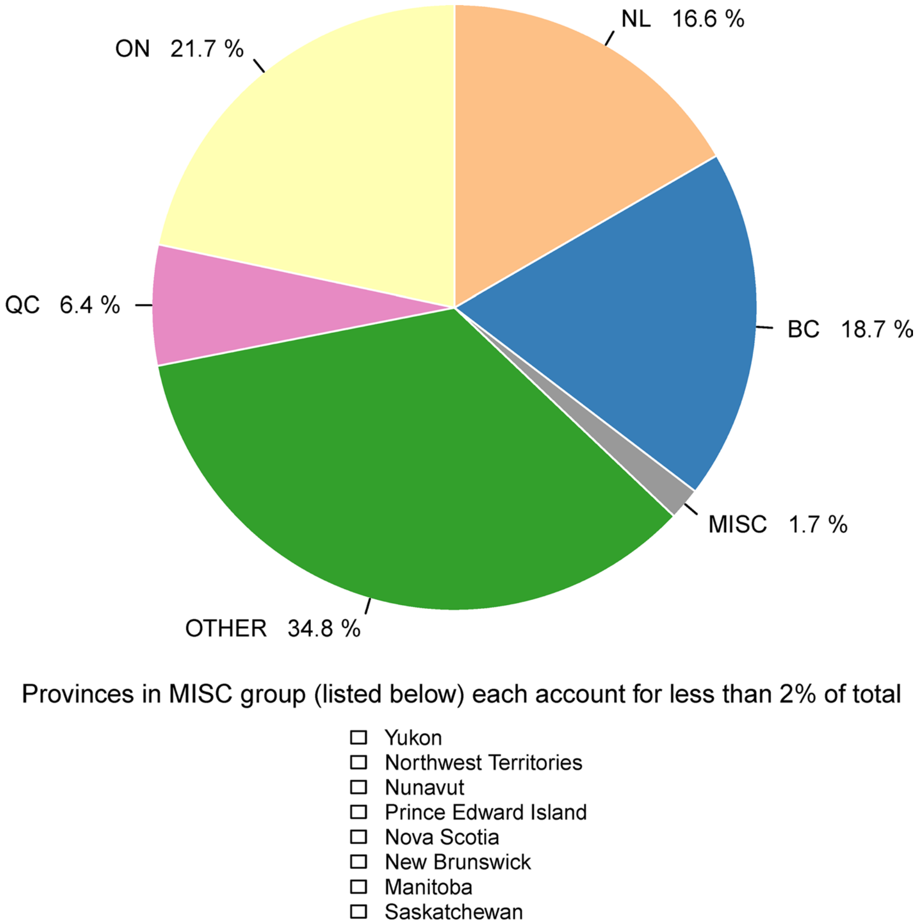


Fig. 5 Natural disaster fatalities by province (1900–2016)

SFDRR monitoring period, requiring significant effort to prevent 555,826 evacuations if Canada's global target is going to be met by 2030.

The disaster injury data ($N=117$) from the CDD can be disaggregated both by province (Fig. 9) and by hazard (Fig. 10). Geographically, Ontario (52.1%), Quebec (6.1%), Saskatchewan (3.5%), and British Columbia (2.2%) cumulatively account for 63.9% of disaster-related injuries. Other Canadian provinces accounted for 0.7% of injuries caused by disasters; and disasters spanning multiple provinces account for the remaining 35.3%. The hazards that caused the most injuries in Canada were tornados (49.3%) and winter storms (37%), with a small number of other hazards also cumulatively contributing 13.7%.

Evacuation figures ($N=117$) could likewise be disaggregated by geography (Fig. 11) and hazard (Fig. 12). The percentage of evacuated individuals were distributed across provinces as follows, Manitoba (30.3%), British Columbia (12.9%), Ontario (9.7%), Quebec, (8.5%), Saskatchewan (5.5%), and multi-jurisdictional disasters accounting for (28.4%); the remaining miscellaneous jurisdictions accounting for (4.7%); with wildfires (48.3%), and flooding (42.7%), accounting for the vast majority of evacuations.

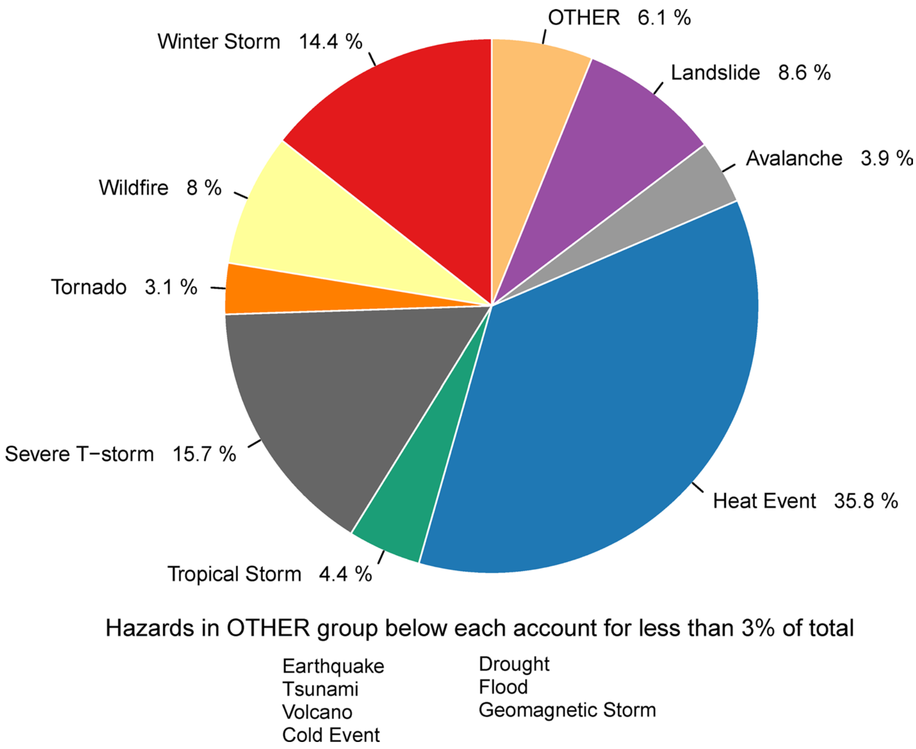


Fig. 6 Natural disaster fatalities by hazard for all provinces (1900–2016)

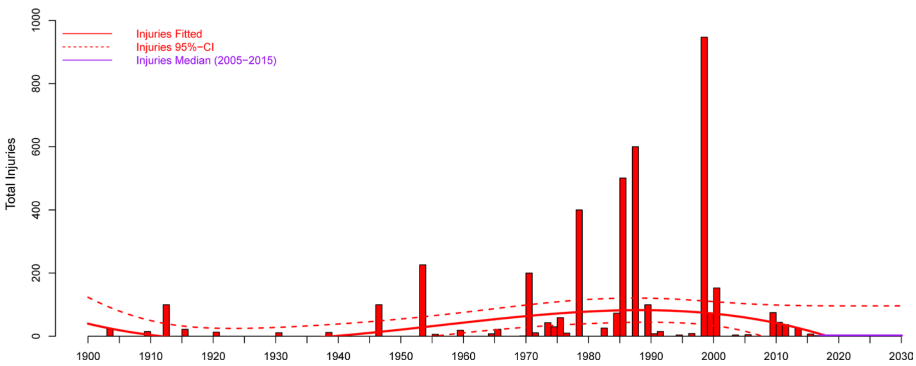


Fig. 7 Natural disaster injuries in Canada (1900–2030)

3.4 Target C: Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030

In the baseline decade, 2005–2015 ($N=11$), Canada experienced an average loss of $216 million annually through the DFAA and $1.69 billion annually through the private sector, totaling $1.9 billion in annual direct economic disaster losses (Fig. 13).

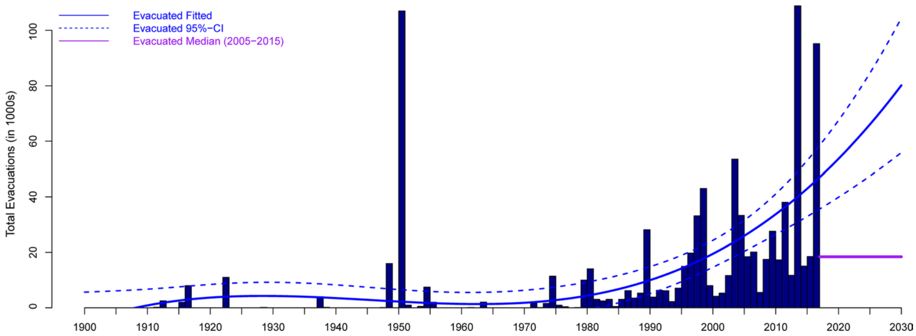


Fig. 8 Natural disaster evacuations in Canada (1900–2030)

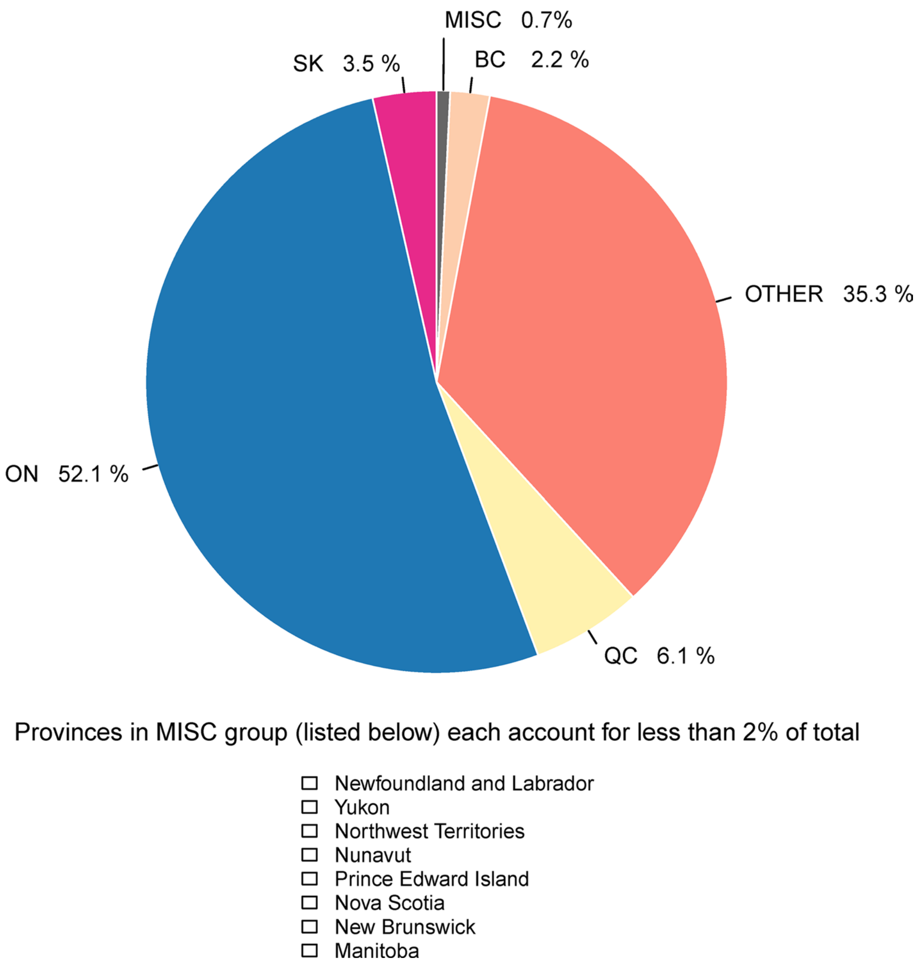


Fig. 9 Natural disaster injuries by province (1900–2016)

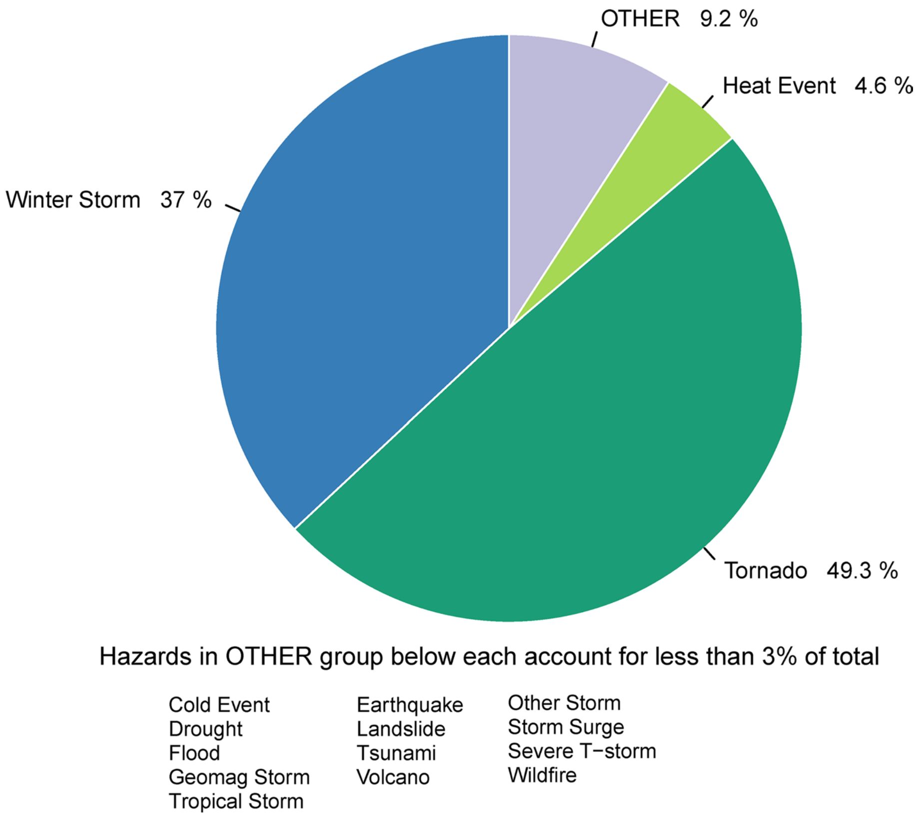
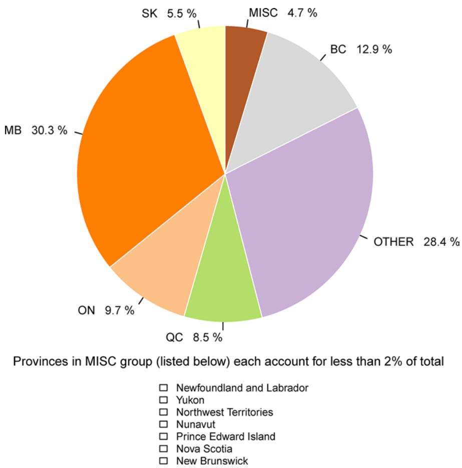


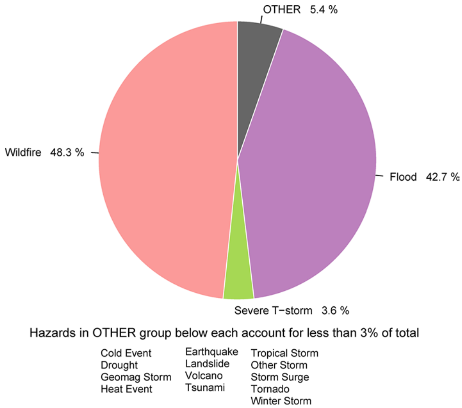
Fig. 10 Natural disaster injuries by hazard for all provinces (1900–2016)

Fig. 11 Natural disaster evacuations by province (1900–2016)



As a percentage of GDP, this totals roughly 0.001% of GDP. If current trends continue ($N=37$), it is expected that the combined direct disaster losses in Canada will total $15.3 billion annually in Canada by 2030, $111.1 billion over the period from 2020 to

Fig. 12 Natural disaster evacuations by hazard for all provinces (1900–2016)



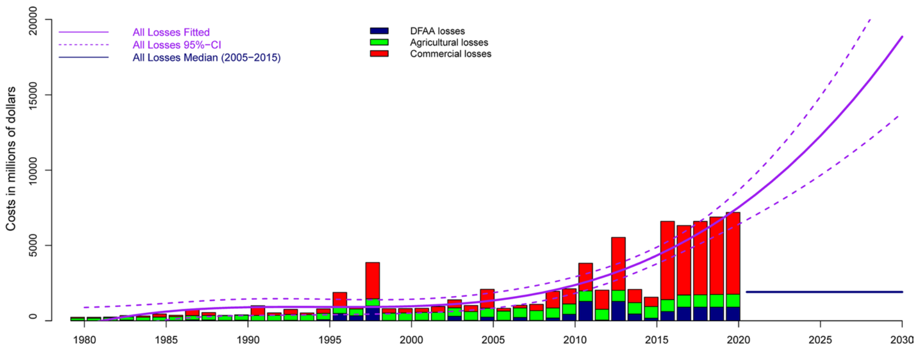


Fig. 13 DFAA, agricultural, and commercial losses in Canada (1980–2030)

2030 ($R^2 = 0.8$, $p < 0.001$), meaning that in order to meet its national target for disaster frequency, Canada would need to reduce projected disaster impacts by \$13.4 billion in 2030 and by \$92.1 billion over the SFRR monitoring decade. Though GDP projections are subject to market uncertainties, it would be highly unlikely that Canada's economy could expand sufficiently to keep pace with the eightfold increase in disaster losses. But as an order of magnitude, Canada would need to prevent roughly an additional \$19.8 billion in disaster economic impacts by 2030 (in current dollars), if it is to meet its national target, assuming an average 2.4% annual inflation rate (OECD 2018a).

Only a subset of the economic loss data could be disaggregated by province (Fig. 14) and by hazard type (Fig. 15). In the case of DFAA events, 47.7% of events were multi-provincial (listed in this case as the first "other" category). For disasters within a single province, Manitoba (17.3%), Saskatchewan (9.7%), Quebec (9%), and British Columbia (8.5%) were most represented in DFAA events. The majority of DFAA events were triggered by flooding (61.5%), followed by winter storms (17.3%), wildfires (9.5%), and severe thunderstorms (8.5%).

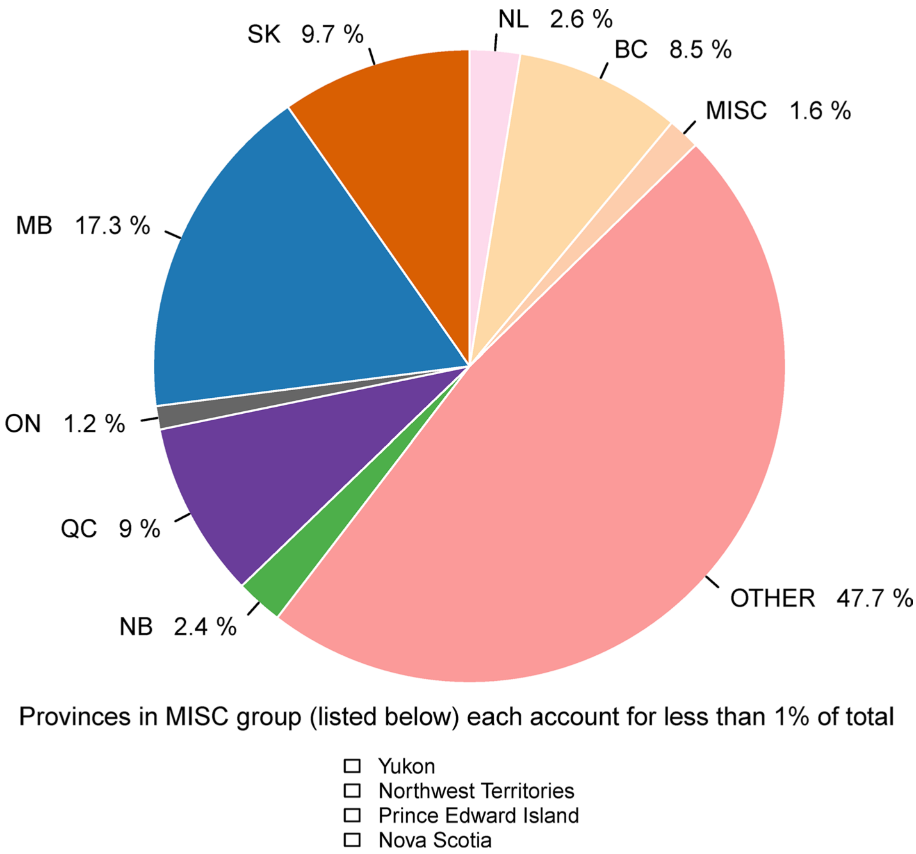


Fig. 14 DFAA costs by province (1970–2016)

3.5 Target D: Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030

In the baseline decade, 2005–2015, there were 120,322,430 customer interruptions ($N=11$). If current trends persist ($n=16$), this is expected to increase ($R^2=0.31$, $p=0.024$); however, given the limited number of data points, this trend does not meet theoretical threshold for prediction. As such, while the general trend in the data appears to be an increasing one, all that can really be gathered for this target is the SFDRR baseline for electrical outages. There were also insufficient data to disaggregate critical infrastructure interruptions further.

3.6 Target E: Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020

In November 2015, the newly elected Prime Minister of Canada instructed the Canadian Minister of Public Safety and Emergency Preparedness, through his Cabinet Mandate Letter to "Work with provinces and territories, Indigenous Peoples, and municipalities to

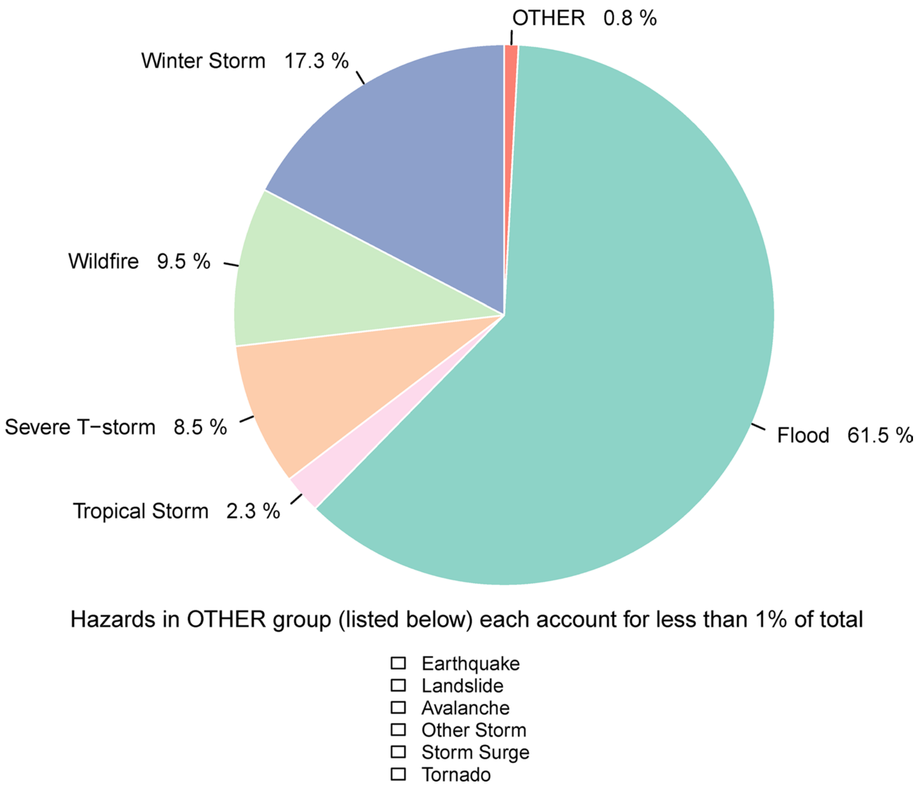


Fig. 15 DFAA costs by hazard for all provinces (1970–2016)

develop a comprehensive action plan that allows Canada to better predict, prepare for, and respond to weather-related emergencies and natural disasters" (Office of the Prime Minister of Canada 2015). This commitment led to the May 2017 announcement by Canadian Federal, Provincial, and Territorial (FPT) Ministers Responsible for Emergency Management approval of the third edition of Canada's national emergency management policy entitled "An Emergency Management Framework for Canada" (PSC 2017b). Although this policy document falls short of a national DRR strategy, at the same May 2017 meeting, FPT Ministers also committed to establish a National Emergency Management Strategy for Canada, which would serve as Canada's domestic strategy for DRR (fulfilling the national-level commitment in the SFDRR). This strategy was approved by FPT Ministers in January 2019 and is structured around five priorities, which roughly align with the SFDRR:

1. Enhancing whole-of-society collaboration and governance to strengthen resilience;
2. Improving understanding and awareness of disaster risks to enable risk-informed decision-making in all sectors of society;
3. Increasing whole-of-society disaster prevention and mitigation activities;
4. Enhancing preparedness activities, to allow for better response capacity and coordination and foster the development of new capabilities; and
5. Leveraging lessons learned and best practices to enhance resilience, including by building back better (PSC 2019).

3.7 Target F: Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this framework by 2030

The Organization for Economic Cooperation and Development (OECD 2018b) tracks Official Development Assistance and net resources flows to developing countries. As such, it is possible to calculate a baseline of net resource flows to developing countries from 2005 to 2015. The mean annual resource flows over the SFDRR baseline period ($N=11$) was $15,750 (million USD 2014). However, it was not possible to determine from the OECD data what percentage of this total was allocated to DRR actions, technology transfers, or capacity building. There is a significant gap in the current Canadian data, which will need to be explored if Canada is to report publically on this target.

3.8 Target G: Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030

In Canada, the National Public Alerting System is a multi-channel FPT all-hazards system that provides emergency management organizations throughout the country with a standard alerting capability to warn the public of imminent or unfolding hazards through such means as radio, cable television, satellite television, and email (PSC 2018). These alerts reach approximately 90 percent of Canadian households subscribed to a television distribution service (CRTC 2019). In Canada, this target suffers from similar limitations as Target E, in that provincial/territorial and local planning efforts to implement the National Public Alerting System are currently unknown; as such, a much more systematic approach to tracking proactive planning efforts for public alerting is required.

4 Study limitations and discussion

4.1 Study limitations

This study has built on existing datasets and methodological guidance and, as such, is useful for framing an initial picture of the current and future disaster impacts in Canada. However, though instructive for policy makers, there are a number of limitations to the approach used, most notably the assumption that the past is an adequate proxy for the future and that the trends will therefore continue along the curvilinear trend lines. The uncertainty associated with this assumption should not be understated. Refsgaard et al. (2014) provide a comprehensive characterization of the various sources of uncertainties associated with environmental modeling procedures of different kinds. The statistical modeling conducted in this study is neither as sophisticated nor predictively powerful as hazard specific, finer resolution, scenario-based modeling advocated by Refsgaard et al. (2014). Bouwer (2013) proposes perhaps the most advanced integrated assessment model for DRR impacts, which considers multiple variables that contribute to the prediction of hazard probability, socioeconomic vulnerability, and asset exposure. Though desirable, more sophisticated modeling requires significantly more data sources than were available for Canada, and fundamentally demands data collection procedures which far exceed the reporting requirements of the SFDRR. Additionally, though it does have its own limitations (see Petrică et al. 2016), the

ARIMA approach used in this study is an established alternative to individual explanatory variable approach, which has been successfully implemented in disaster contexts (Dore 2003; Narayanan et al. 2013). Given that our objective in this research was to test and push the limits of the data collected as part of SFDRR reporting methodology, these models fell outside the scope and feasibility of this research.

A second challenge with this assumption of historical predictability manifests in the treatment of small-scale extensive and large-scale intensive risks,[1] especially in the face of significant uncertainties posed by climate change, which are likely to increase both of these types of extremes. In the case of persistent small-scale extensive risks, the data that currently exist in Canada do not track events that do not meet minimum CDD or insurance industry thresholds. It may be the case that losses from extensive risks, including drought, that do not meet thresholds for current data collection practices cumulatively account for significant losses, which are undocumented at present. A similar issue exists at the opposite end of the disaster impact scale. Catastrophic-scale events with recurrence rates that extend beyond the current dataset time horizons, such as megathrust earthquakes, are unrepresented in the projections. This is of particular concern as Canada has two densely populated seismically active regions; a major earthquake along either the west or east-central Canadian faults could cause losses an order of magnitude beyond any single event in the current data and seriously compromise the integrity of the projections generated by the curvilinear extrapolations. Improving data collection and integrated risk modeling for these events is a crucial step in improving the accuracy of disaster projections.

Another significant limitation of the study is the quantity and quality of the data. For Target 0, the disaster frequency data were among the most robust in this study. However, the data entries in the CDD from before 1998 were gathered retrospectively so these are likely underestimates of actual events. Within the CDD, fatalities tracked for Target A are entered using the definition "the number of people killed due to a specific [disaster] event." This definition provides little clarity on whether direct or indirect fatalities are being considered and also, what the time span or cutoffs should exist for surveillance. Also, the Canadian data are not inclusive of the UNISDR category of "missing persons." The CDD entries for Target B, tracking injury, and evacuation definitions are equally vague. Further, the CDD does not track the number of houses/dwellings impacted by disaster, so the Canadian data does not cover this UNISDR sub-indicator. The most consistent economic loss data tracked in Target C come from the DFAA. However, these data are triggered on a per capita threshold, based on provincial/territorial population, so a $10 million disaster would be represented if it occurred in the province of Manitoba, but if it occurred just across the border in Ontario, it would need to be almost ten times as large to be counted. The insurance losses likewise have an independent definition of disaster event, requiring single-event losses to exceed $25 million, though this is at least consistent across provinces and territories. The agricultural loss data have no minimum threshold, so they account both for the small extensive risk events and for the single large extensive events. Additionally, there were very limited data on critical infrastructure and essential service disruption data in Canada for Target D. Exacerbating these specific limitations were the missing years in

[1] The UNISDR defines "extensive risk" which is used to describe the risk associated with low-severity, high-frequency events, mainly but not exclusively associated with highly localized hazards. "Intensive risk" is used to describe the risk associated with high-severity, mid- to low-frequency events, mainly associated with major hazards.

the time-series datasets, which required statistical modeling approaches to fill missing data, these techniques are useful, but introduce additional uncertainties into the modeling.

Finally, there are some limitations with forecasting using polynomial regression models. Although the method generally provides a good fit for the data, there is an increasing probability of errors as the forecast extends further into the future. For example, with disaster fatalities, although a forecast may project zero fatalities sometime in the future, it is unlikely to be exactly zero in any given year. Also, a large number of data points are needed for a reliable forecast, which can be an issue when forecasting using data such as electrical outages (Target E).

4.2 Discussion

The objective of this study was to explore DRR trends in Canada by applying the United Nations standard methodology and to employ a statistical forecasting methodology to estimate the changes in target indicators during the SFDRR monitoring decade (2020–2030). When the results of the SFDRR baselines data are compared against the modeling forecast data, it is clear that Canada has a challenging road ahead if it is to meet its SFDRR commitments by 2030. All told, Canada will need to prevent 88 hazard events from becoming disasters; keep the disaster fatalities rate near zero; avoid 4712 disaster-related injuries; prevent 555,826 people from being evacuated; avoid $92.1 billion in disaster losses; and presumably protect significant sources of critical infrastructure and essential services from disruption. Additionally, Canada would need to also continue to institutionalize DRR planning, target foreign aid to DRR in developing nations, and expand its public alerting system.

The findings of our study were largely consistent with the international experience of other developed G7 and OECD countries, which saw the majority of disaster impacts consisting of financial losses and evacuations, with comparatively low disaster-related mortality and morbidity rates (IPCC 2012, 2014; UNISDR 2015a). Given the level of technological advancement and interdependence in Canada, we would also anticipate seeing mounting critical infrastructure and essential service disruptions as a result of disasters moving forward. This trend is likely already in place in Canada; however, we lacked the data to confirm this prediction. We also suspect that the various disaster-related improvements to the National Building Code of Canada played an important role in decreasing disaster morbidity and mortality figures over time. However, given that provinces and territories voluntarily adopt the National Building Code along disparate timelines, and that the actual return on these amendments is further delayed by building construction time and the actual occurrence of a disaster event, these benefits are challenging to accurately assess at the national scale.

The SFDRR is focused on both managing existing disaster risks and preventing the development of new risks. Given the findings of this study, Canada's existing disaster risk management investments would presumably have to increase in volume or efficacy to keep pace with these trends. Even with an immediate influx of significant new and effective disaster risk management actions, it is unlikely Canada would be able to meet its SFDRR baselines, given the time it takes to both construct and/or implement DRR measures. That said, with some relatively straightforward policy and regulatory changes, Canada's recently announced $180 billion "Investing in Canada Plan" could prevent the development of over $180 billion in new risk exposure. As such, a new line of thinking should be added to

Canada's efforts to manage disaster risks, not just building back better, but also building smart to start with.

5 Conclusion and recommendations

5.1 Conclusion

This article represents an important contribution to the Canadian, and international, literature on DRR for three reasons. First, it is among the first attempts in the literature to implement the UNISDR methodology in its entirety at the national level and provides notes on the experience and limitations of the methodology in the Canadian context; though it should be noted, this paper is not Canada's official reporting, which will be done by the Government of Canada through the UNISDR. Secondly, it provides Canadian decision-makers with an estimate of the gulf between the SFDRR baselines and the projected disaster impacts at the end of the SFDRR period, if current conditions persist unmitigated. This information is a crucial input informing the scale and prioritization of domestic DRR efforts in Canada. Finally, we believe our open-source software program that automates SFDRR baseline and projection calculations will provide consistent, ready-to-use, theoretically rigorous calculations, based on the structure of existing Canadian datasets. This program could assist with Canada's biennial reporting to the UNISDR and could easily be modified and used by any SFDRR signatory nation to assist with their reporting and trend projections.

5.2 Recommendations

Targets A–C and 0 The UNISDR methodology contains a total of 38 indicators and sub-indictors for measuring progress against the targets of the SFDRR. This study has illuminated significant data gaps in Canada's existing data sources for these indicators and sub-indicators. These gaps would need to be filled in order to develop a more comprehensive picture of Canada's SFDRR progress. However, nearly complete data do exist for the disaster impact targets A–C and 0. If Canada were to expand its data collection activities through the CDD, it could very quickly address the limited data gaps in targets A–C and 0.

Target D It is clear that the Canadian approach of considering critical infrastructure reporting as a matter of national security rather than a matter of DRR negatively impacts transparency and impact monitoring. If stakeholders in critical infrastructure were to adopt a comparable approach to the IBC and CatIQ aggregation approach for insurance losses, this might allow the industry to respect concerns about security and competitiveness, while still contributing to the national picture of disaster impacts in Canada.

Target E Each province and territory has jurisdiction for legislating emergency management and DRR planning at the local level. If each jurisdiction were to report on the percentage of compliant local governments, as part of biennial SFDRR processes, this data could quickly be filled in.

Target F The government of Canada does not currently seem to track international DRR ODA flows. However, this is a crucial input into the global SFDRR monitoring, so progress needs to be made in this regard.

Target G There is some upcoming uncertainty as to the future of the current system based on a decision of the Canadian telecommunications regulator to explore stronger public ownership of the National Public Alerting System.

Compliance with ethical standards

Conflict of interest In additional to his doctoral studies at Royal Roads University, through which this research was conducted, Matthew Godsoe is an employee of Public Safety Canada.

References

Aitsi-Selmi A, Egawa S, Sasaki H, Wannous C, Murray V (2015) The Sendai Framework for Disaster Risk Reduction: renewing the global commitment to people's resilience, health, and well-being. Int J Disaster Risk Sci 6(2):164–176

Bouwer LM (2013) Projections of future extreme weather losses under changes in climate and exposure. Risk Anal 33(5):915–930

Briceño S (2015) Looking back and beyond Sendai: 25 years of international policy experience on disaster risk reduction. Int J Disaster Risk Sci 6(1):1–7

Canadian Radio-Television and Telecommunications Commission (2019) Emergency alert messages and the National Public Alerting System. Retrieved 25 March 2019 from: https://crtc.gc.ca/eng/television/services/alert.htm

de la Poterie AT, Baudoin MA (2015) From Yokohama to Sendai: approaches to participation in international disaster risk reduction frameworks. Int J Disaster Risk Sci 6(2):128–139

Dore MH (2003) Forecasting the conditional probabilities of natural disasters in Canada as a guide for disaster preparedness. Nat Hazards 28(2–3):249–269

Government of Canada (GOC). (2007). Emergency management Act. S.C. 2007, c. 15

Intergovernmental Panel on Climate Change (IPCC) (2012) IPCC special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX*)*. IPCC, Geneva

Intergovernmental Panel on Climate Change (IPCC) (2014) The IPCC fifth assessment report: impacts, adaptation, and vulnerability (Working Group II). IPCC, Geneva

International Monetary Fund (2018) Report for selected countries and subjects: Canada. World Economic outlook database: April 2018. Accessed from: https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/index.aspx

Ismail-Zadeh AT, Cutter SL, Takeuchi K, Paton D (2017) Forging a paradigm shift in disaster science. Nat Hazards 86(2):969–988

Lindsay J (2009) Emergency management in Canada: near misses and moving targets. Comparative Emergency Management Book Project, Emmitsburg

Narayanan P, Basistha A, Sarkar S, Kamna S (2013) Trend analysis and ARIMA modelling of pre-monsoon rainfall data for western India. CR Geosci 345(1):22–27

Office of the Prime Minister of Canada (2015) Mandate letter to the minister of public safety and emergency preparedness. Retrieved from: https://pm.gc.ca/eng/minister-public-safety-and-emergency-preparedness-mandate-letter. Accessed 22 Apr 2018

Organization for Economic Cooperation and Development (OECD) (2018a) Inflation (CPI) (indicator). https://doi.org/10.1787/eee82e6e-en. Accessed on 02 Apr 2018

Organization for Economic Cooperation and Development (OECD) (2018b) Statistics on resource flows to developing countries. Retrieved 10 January 2019 from: http://www.oecd.org/dac/stats/statisticsonresourceflowstodevelopingcountries.htm

Parliamentary Budget Officer (PBO) (2016). Estimate of the average annual cost for disaster financial assistance arrangements due to weather events. Government of Canada, Ottawa, ON

Petrică, AC, Stancu S, Tindeche A (2016) Limitation of ARIMA models in financial and monetary economics. Theor Appl Econ 23(4):19–42

Public Safety Canada (PSC) (2017a) Canadian Disaster Database. Retrieved 10 Oct 2017 from Public Safety Canada Web site: http://cdd.publicsafety.gc.ca

Public Safety Canada (PSC) (2017b) 2016–2017 Evaluation of the disaster financial assistance arrangements. Government of Canada, Ottawa

Public Safety Canada (PSC) (2017c) An emergency management framework for Canada, 3rd edn. Government of Canada, Ottawa

Public Safety Canada (PSC) (2018) National public altering system. Retrieved 10 January 2019 from: https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/mrgnc-prprdnss/ntnl-pblclrtng-sstm-en.aspx

Public Safety Canada (PSC) (2019) An emergency management strategy for Canada. Government of Canada, Ottawa

Refsgaard JC, Madsen H, Andréassian V, Arnbjerg-Nielsen K, Davidson TA, Drews M, Hamilton DP, Jeppesen E, Kjellström E, Olesen JE, Sonnenborg TO, Trolle D, Willems P, Christensen JH (2014) A framework for testing the ability of models to project climate change and its impacts. Clim Change 122(1–2):271–282

Statistics Canada (StatsCan) (2017) Census profile: 2016 census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa. Released November 29, 2017

United Nations General Assembly (UNGA) (2017) Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction. Seventy-first session, 19 (c). New York, UNISDR

United Nations International Strategy for Disaster Reduction (UNISDR) (2011) Revealing risk, redefining development. Global assessment report on disaster risk reduction. United Nations Office for Disaster Risk Reduction (UNISDR), Geneva

United Nations International Strategy for Disaster Reduction (UNISDR) (2012) Towards a Post-2015 framework for disaster risk reduction. United Nations Office for Disaster Risk Reduction (UNISDR), Geneva

United Nations International Strategy for Disaster Reduction (UNISDR) (2015a) Making development sustainable: the future of disaster risk management. Global assessment report on disaster risk reduction. United Nations Office for Disaster Risk Reduction (UNISDR), Geneva

United Nations International Strategy for Disaster Reduction (UNISDR) (2015b) Sendai Framework for Disaster Risk Reduction 2015–2030. UNISDR, Geneva

United Nations International Strategy for Disaster Reduction (UNISDR) (2015c) Proceedings third world conference on disaster risk reduction. UNISDR, Geneva

United Nations International Strategy for Disaster Reduction (UNISDR) (2017) Technical guidance for monitoring and reporting on progress in achieving the global targets of the Sendai Framework for Disaster Risk Reduction: collection of technical notes on data and methodology. UNISDR, Geneva