Climatic Change (2017) 141:259–271
DOI 10.1007/s10584-016-1892-x

Can wildlife surveillance contribute to public health preparedness for climate change? A Canadian perspective

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Received: 18 July 2016 / Accepted: 21 December 2016 / Published online: 11 January 2017

Abstract Early warning systems for climate change adaptation, preparedness and response will need to take into consideration the range of factors that can drive risk and vulnerability. There are no data from which to nominate the most effective, efficient and reliable wildlife health signals for public health planning, but there is growing opinion that wildlife health could signal public health vulnerability related to climate change. The objective of this commentary is to explore the potential for wildlife to contribute to climate change early warning for public health protection in Canada. Wildlife impact many determinants of human health through both direct and indirect mechanisms; several of which are strongly interconnected. There is a long history of wildlife serving as bio-sentinels for environmental pollutants and pathogens. Wildlife health could support public health threat detection, risk assessment and risk communication by detecting and tracking infectious and non-infectious hazards, being bio-sentinels of effects of new or changed hazards, providing biologically understandable information to motivate changes in personal risk behaviours and providing insights into new and unanticipated threats. Public health risk communication and strategic planning priorities for climate change could benefit from a wildlife health intelligence system that collects data on incidents of disease and hazard discovery as well as information on social and environmental conditions that affect risk perception and likelihoods of human exposure or harms.

1 Introduction

The effects of climate change are already being witnessed in Canada. Actions are needed to reduce vulnerability and risk (PHAC 2014) because the anticipated consequences of climate change are occurring faster than expected (Mascarelli 2008). The Government of Canada has recommended that public health strives to identify the most vulnerable populations in advance of harm to prevent

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and adapt to current as well as unanticipated and unforeseen threats from climate change (PHAC 2014). Although most provincial, territorial and federal governments are investing efforts into climate change planning, efforts to address climate change and health remain uneven across sectors. Incomplete knowledge of health risks and limited awareness of best health protection practices are barriers to climate change adaptation in Canada (Health Health 2008). The objective of this paper is to explore the potential for wildlife to contribute to climate change early warning for public health protection in Canada. To address this objective, we review how wildlife influence public health outcomes and propose situations where wildlife may provide early warning clues of community threats and vulnerability in advance of observed public health impacts.

Variability in geographic and population vulnerability, combined with the rapid pace of change, are creating new challenges and surprises for public health leaders (Frumkin et al. 2008). In order to achieve effective climate change preparedness, it is important to not only have the best current intelligence but also an indication of what the future may bring. Given uncertainties associated with climate change, systematically collected environmental early warning signals could reduce public health surprises.

The primary role of an early warning system is to empower individuals, communities and/or organizations to respond in a timely and appropriate manner to avoid, reduce or mitigate harm. Warning occurs when a change in risk or vulnerability status is revealed and that change is rapidly communicated to those able to respond (Yamin et al. 2005). The Canadian Public Health Association has emphasized the need to identify health indicators for conditions plausibly related to ecological change as part of early warning or sentinel conditions to be monitored (CPHA 2015). The Public Health Agency of Canada recognizes the value of integrating animal, human and ecosystem health when developing preventative measures for climate change adaptation (PHAC 2013a). Given wildlife's role as sources of new and emerging infections; their position at the interface between the natural environment, domestic animals and people; and their intimate and ongoing interaction with their environment, it can be anticipated that wildlife will signal changing epidemiological patterns important to public health.

We began to address our objectives through a scoping literature review using PubMed, Google Scholar and Web of Science. Preliminary searches were designed to elucidate evidence on the role of wildlife as climate change sentinels for public health with emphasis on Canada. Additional literature was identified through forward and reverse citation searching. We found no data from which to nominate the most effective, efficient and reliable wildlife health signals of public health risk or vulnerability related to changing climate. This reflects the following: (i) the challenge of deciding the proportional contribution of climate change to health outcomes, as many of the outcomes of concern are influenced by other macro and micro-factors; (ii) the dearth of assessments of the utility of climate change sentinels or early warning surveillance; and (iii) insufficient time for surveillance systems to have been operating to determine if wildlife health changes precede human health effects of climate change. Although effective integration of human and animal disease information is widely recognized as the key to the successful emerging disease surveillance, few surveillance systems using animals as public health sentinels have been systematically evaluated and even fewer have been assessed for public health usefulness (Vrbova et al. 2010).

Despite this lack of evidence, we found a growing opinion in the literature that animals, particularly wildlife, could provide early warning of public health concerns related to climate change. Some of this opinion is based on the use of wildlife for other early warning purposes (e.g. emerging infectious disease, pollution) and from observations of changing epidemiological situations related to climate change. The remainder of this paper aims to situate wildlife health within a public health framework for early warning of climate change effects.

2 Discussion

2.1 Where wildlife relates to public health concerns about climate change

Wildlife impact many environmental and social determinants of human health through both direct and indirect mechanisms; several of which are strongly interconnected (Table 1). While all of these health determinants may be influenced by climate change, the potential for wildlife to inform public health has been insufficiently investigated.

There is a long history of wildlife serving as bio-sentinels for the effects and distribution of environmental pollutants and pathogens (Kuiken et al. 2005; Reif 2011). These are the most widely discussed public health roles for wildlife and have a history of inspiring regulatory change. Given the projections for changing distributions and burdens of pathogens and pollutants in the face of climate change, the role of wildlife as bio-indicators is anticipated to increase. There are current expectations and experience supporting the use of wildlife signals to forecast changing public health risk from food-, water- and air-borne infections, particularly on the use of wildlife as environmental markers of the introduction, distribution and abundance of infectious hazards. The mechanisms through which these changes will occur with climate change depend on the specific host, agent and environment, but are broadly classified as (i) changing abundance or distribution of the host, pathogen or vector; (ii) altering lifecycle traits of the host, pathogen or vector; and (iii) impacting the physiological capacity of the host, pathogen or vector (Acevedo-Whitehouse and Duffus 2009; Brooks and Hoberg 2007; Gallana et al. 2013; Warren and Lemmen 2014). Climate change is generally expected to shift host, vector and pathogen species northward (Harvell et al. 2002; Walther et al. 2002), resulting in new ecological relationships that can affect disease dynamics. Examples of

Table 1 Examples of the contribution of wildlife to some determinants of public health in Canada

Public health determinant (Public Health Agency of Canada (PHAC) 2013b)	Examples of influence of wildlife on determinant
Income and social status	– Economic resource (consumptive and non-consumptive use) – Social status in hunting communities and recreational users of nature
Employment/working conditions	– Sense of identity and purpose (natural resource workers; aboriginal cultural connections) – Healthy working conditions (safe non-built environments; zoonoses)
Social environment	– Promotion of healthy lifestyle choices (recreational fishing, hunting and other nature uses) – Group membership (wildlife watching, hunting etc.)
Physical environments	– Source of commercial, community and country food – Biodiversity and disease regulation – Source of pathogen and pollution exposure in natural settings – Trauma – Ecosystem integrity
Personal health practices and coping skills	– Mental health value of natural spaces and animal connections – Confidence in safe use of outdoor recreation activities
Healthy child development	– Connectivity with nature – Traditional foods
Culture	– Spiritual connection with wildlife – Cultural identity and values

climate-related ecological change leading to epidemiological change in wildlife-associated infectious disease include (i) the spread of Lyme disease vectors by birds that have begun to shift their migratory timing and locations (Jenni and Kery 2003; Ogden et al. 2008; Ogden et al. 2009), (ii) warmer summer temperatures in the Canadian Arctic have shortened the lifecycle of a muskoxen lung nematode larvae from 2 to 1 year (Kutz et al. 2005) and (iii) heat stress is negatively influencing rates of mortality from parasitic and infectious disease in moose in the northern USA (Murray et al. 2006).

New, re-emerging, invasive or introduced pathogens and vectors are often first found in wildlife which subsequently maintains them in environments, causing human exposures (Daszak et al. 2000; Taylor et al. 2001). Highly pathogenic influenza (Parmley et al. 2009), hantavirus (Drebot et al. 2000), Lyme disease (Ogden et al. 2008; Ogden et al. 2009), West Nile virus (Eidson et al. 2001) and a suite of re-emerging food-borne diseases (Charron 2002) are but a few recent examples where Canadian wildlife provided information to direct surveillance, public and physician alerts and disease management strategies. Many emerging infectious disease warning systems use information about wildlife events for disease intelligence and risk assessment at the animal/human/ecosystem interface to improve early warning and support relevant response. Wildlife health data has helped to identify and prioritize the allocation of public health effort and resources to communities or individuals at higher risk of pathogen exposure.

Changes in temperature, precipitation and weather patterns will alter the pathways, persistence and concentrations of pollutants entering the environment via air and ocean currents (Burek et al. 2008). Increased use of pesticides to control invasive weeds, ice melt mobilizing chemicals and release of chemicals from sediments are raising concerns about changing exposure and effects of pollution, especially for children (USEPA 2013). Wildlife have a well-established history as biologically meaningful sentinels of health risks from environmental pollutants. Wildlife have revealed thyroid and other endocrine disorders, metabolic diseases, altered immune function, reproductive impairment, developmental toxicity, genotoxicity and cancer linked to environmental contaminants in Canada, such as seen in birds in the Great Lakes (Hebert et al. 2000) and whales in the St. Lawrence River (Bossart 2011). Climate change alterations in food webs, lipid dynamics, ice and snow melt and organic carbon cycling are expected to affect wildlife exposure to contaminants (Noyes et al. 2009). Arctic wildlife and fish are at the highest potential risk for certain persistent organic compounds and organohalogen contaminants (Letcher et al. 2010). Sentinel species data are unlikely to be the only information used to evaluate public health concerns, but they do contribute to the weight of evidence to identify and assess early warning signals requiring further investigation (van der Schalie et al. 1999).

There is growing concern and evidence that increased surface temperatures, lower pH, changes to vertical mixing, upwelling, precipitation and evaporation patterns in marine and freshwater systems will continue the trend of more frequent and significant harmful algae blooms (Moore et al. 2008; Paerl and Paul 2012). Wildlife (including fish) mortality events associated with these blooms are becoming increasingly recognized including die-offs resulting from exposure to saxitoxin, domoic acid, brevetoxin and other algal toxins (Burek et al. 2008; Glasgow et al. 2001), suggesting their value as indicators of the presence of harmful algae in marine and freshwater environments.

The issue of food insecurity, as a function of climate change, has been well investigated in the Arctic where effects of climatic extremes have impacted the region's adaptive capacity (Ford 2008; Wesche and Chan 2010). Changes to wildlife migration routes, population size, body condition and infection and contamination status are affecting northern food security as well as economic opportunities from wildlife hunting. Sustainable wildlife management is a cornerstone to aboriginal food security, but poor wildlife health and changing wildlife distribution and abundance are major contributors to Canada's northern food insecurity crisis. The battle against diabetes and heart disease in indigenous communities relies, in part, on access to safe, traditional, wildlife-based foods (Patchell and Edwards 2014). Recommendations for seafood consumption to combat heart disease depend on safe and abundant fish to eat (Mozaffarian and Rimm 2006). Rural and aboriginal communities have the human right to adequate food, including the right to feed themselves and to participate in decisions about their food system, yet food safety assurances are not equitable for those who purchase versus harvest their food. For those Canadians reliant on wildlife for food, decreased food security may be the result of decreased access to historical hunting and fishing grounds due to changing environmental conditions (i.e. thin ice) (Ford 2008) or climate-mediated changes in wildlife abundance and distribution (Furgal and Seguin 2006; Humphries et al. 2004). For example, the recent northward range expansion of the winter tick, *Dermacentor albipictus*, in moose and caribou is attributed to landscape change (fires) together with climate warming (Kutz et al. 2009). This tick can result in large-scale die-offs of moose, limiting access to a critical food species.

Traditional harvest of wildlife is also an economically important activity. Wildlife harvest in Nunavut, for example, is worth over $40 million a year (Statistics 2001). Hunting, trapping and fishing not only contribute to aboriginal culture and rights and the quality of life of many Canadians, but also generate $14–15 billion annually (POC 2015). The value of the seafood sector (excluding aquaculture) was near $15 billion in 2012, while the recreational fishery in 2010 was responsible for $8.3 billion in spending. Over half of all Canadians take part in non-consumptive wildlife-oriented activities, like bird or whale watching. Direct tourist expenditures on eco-tourism in the province of British Columbia alone are approximately $1.5 billion dollars per year (WTABC 2016).

Wild animal contributions to ecological service far outweigh their direct economic benefits. When ecosystem services are compromised, economic and health impacts cost Canadians, industry and governments. Biodiversity benefits people through more than just its contribution to material welfare and livelihoods (MEA 2005). It contributes to security, resiliency, social relations and freedom of choices and actions. Some of these services are very tangible. Bats, for example, save the agriculture industry billions of dollars in pesticide use because of their voracious consumption of insect pests (Boyles et al. 2011). Other ecological services are more difficult to quantify. Many Canadians' sense of identity and belonging is linked to their historic and ongoing use of wildlife for work, recreation and spiritual purposes. First Nation, Metis and Inuit peoples not only have this close connection to wild animals but also have treaty and other legal rights that ensure Canada maintains accessible, safe and healthy wild populations.

Finally, wildlife contribute to other determinants of public health such as social status, culture and working conditions. Vibrant wildlife populations provide people with positive lifestyle choices related to outdoor activity, food sources, community activity, occupational options and cultural belonging. There is growing evidence of the importance of nature in people's sense of community and mental health (Berto 2014). Maintaining abundant, accessible and safe wildlife populations will sustain their contributions to the social determinants of health and community resilience. The ability of people and organizations to face and manage adverse conditions, emergencies or disasters (known as community coping capacity) is provided by nature and people (Keim 2008), and failure to direct attention towards ecological determinants of vulnerability is a risky strategy.

2.2 Potential for public health early warning from wildlife in a changing climate

Risk knowledge comes from the combined understanding of the nature of hazards and vulnerabilities at a particular location. In this paper, we have taken from public health and disaster planning definitions of vulnerability to identify four key determinants of vulnerability: (i) the character of the hazard(s) of concern, (ii) the nature and magnitude of harm(s) that can result, (iii) the probability of exposure to the hazard and (iv) the ability of the population(s) of concern to cope with the harm. Wildlife health information can help public health managers anticipate or mange vulnerability to climate change effects under five scenarios based on these determinants. The following scenarios serve to point out how wildlife data may be an aid to learning about key elements of community vulnerability. There are not mutually exclusive but rather serve as general categories to illustrate the variety of ways wildlife data can be of service to public health planning for climate change.

2.2.1 Risk management scenario: public health managers are fully aware of the nature of the hazard and community vulnerability

In this scenario, efforts should focus on understanding how a known environmental hazard is changing in distribution or abundance in the environment in response to climate change or management responses, as well as using signals from wildlife to inspire public or regulatory response to a known hazard by influencing risk perception.

When wildlife are the source of the hazard (e.g. food-borne pollutant or vector-borne disease), public health harm can most effectively be reduced by reducing human exposure to the hazard. This can be attempted through modifying the prevalence of the hazard in the wildlife or by inducing human behaviours that reduce the likelihood of exposure. There are few effective measures other than mass depopulation to achieve the former for infectious diseases once a pathogen enters a wild population; mass treatment, immunization and isolation are rarely possible in free ranging animals (Wobeser 2002). Depopulation must be done with caution due to public concerns, losses of the positive contributions of wildlife to social determinants of health and unanticipated effects that can arise from culling. For example, culling coyotes over pathogen concerns (e.g. *Echinococcosis*) can result in compensatory reproduction which in fact increases the coyote population and introduces more susceptible young animals into the population (Knowlton et al. 1999). For pollution, source control is the principle option.

Human behaviour modification can include avoiding consumption of commercially or non-commercially harvested fish and wildlife with known harmful levels of hazards in edible portions, use of vector repellents in areas of known vector-borne pathogens and avoiding high-risk habitats for outdoor recreation or work due to the presence of hazards in that environment. To inspire people to use these and other risk avoidance behaviours, they must first perceive the risk to be sufficient to warrant action. Wildlife signals may help society recognize a risk by demonstrating the presence or effect of an environmental hazard in another living being. Recognition of a risk is an important societal response affecting individuals' risk perceptions (Decker et al. 2010) and, therefore, motivations to respond to a risk.

The selection of specific indicators to monitor will depend on the hazard public health has prioritized for specific communities/regions. By tracking known hazards, it is easier to target risk reduction methods to more highly vulnerable communities. For example, knowing that Inuit communities depend on wildlife for food and anticipating increased infections and parasitic diseases in Arctic wildlife (Kutz et al. 2013) suggests investment in monitoring northern wildlife pathogens and parasites in order to provide more specific food safety information to communities is sound public health policy.

2.2.2 Coping assessment scenario: risk managers are uncertain how a community can cope with known hazards

In this scenario, the contributions of wildlife to social determinants of health that help individuals and communities cope with emerging threats (e.g. income, food security, cultural cohesion) are monitored, assessed and managed. In natural resource-dependent communities, this would require monitoring changes in the presence, abundance or safety of wildlife used by the community and relative changes in wildlife contribution to the determinants of health.

The nature, amount and variability in biodiversity determine the sustainability and flow of ecosystem services and, therefore, is a key determinant of a community's capacity to adapt to future health challenges, whether they arise from novel pathogens, emerging non-communicable diseases or loss of ecological services (Keune et al. 2013). Canadian coastal community vulnerability to climate change, for example, will be mediated through changes in biodiversity affecting cultural and economic uses of natural resources and landscape changes affecting the distribution and amounts of biological and abiotic pollution in the environment (NR Canada 2014). There is little evidence that public health is partnering with natural resource agencies to integrate an understanding of environmental characteristics (in this case, wildlife ecology and health) in community vulnerability assessment in Canada. Public health attention on the environment, in terms of climate change, has largely centred on urban air quality, zoonoses and infrastructure defences against extreme weather.

Canada's 2013–2016 Federal Sustainable Development Strategy recognized the need to protect and sustain the links between nature, economy and society (EC 2016). Like the UN 2030 Agenda for Sustainable Development (UN 2015), this strategy is predicated on the idea that prosperity and human well-being cannot be achieved without regard to the planet and partnerships. Community adaptation to climate change requires an all-of-government approach, but the gulf between government agencies seems exceptionally wide at the nature-economy-society nexus. One reason is the diffusion of legislation and authority to manage this nexus. Another reason is the lack of research or government programs that have determined the proportional contribution of wildlife to community resilience or the values and services they provide Canadians.

Declining harvests of wildlife species and the discovery of environmental contaminants in traditional, wildlife-based foods have inspired concern in indigenous communities. Given the importance of autonomy over food choice, ability to express cultural traditions and availability of safe, secure food to community resilience, anticipating the effects of climate change on fish and wildlife will be critical for protecting northern and rural community coping capacity. However, there is inadequate integration of wildlife health information in community adaptation planning. Significant regionally specific work would be required to nominate indicators for this scenario due to the gap in research establishing the contribution of wildlife to social determinants of health. An exception to this is monitoring the abundance, quality and distribution of fish and wildlife used for important commercial and non-commercial harvests.

2.2.3 Hazard detection and monitoring scenario: variation in vulnerability is primarily driven by differences in exposure to known hazards

In this scenario, the goal is for wildlife to provide reliable signals of the environmental distribution and abundance of known hazards and to yield information on the likelihood of human exposure by understanding human-wildlife interactions.

General diagnostic and field investigation services have been central to identifying new and emerging health impacts from environmental pollution and have been effectively deployed to assess die-offs, outbreaks and unusual pathology or productivity in animals (Stephen and Stitt 2014). They have also been instrumental in pathogen discovery and risk assessments for emerging diseases. Bolstering capacity for general diagnostics and field investigations at climate change sensitive locations in Canada would require linking surveillance planning with climate models and evolving current approaches to surveillance.

Animals have a long history serving as sentinels for environmental hazards (Reif 2011). Animal sentinels have the potential to document changes in host ranges, host responses to pathogens and the relationships between hosts (Halliday et al. 2007). Rabinowitz et al. 2005 noted there are no evidence-based guidelines for the use of animal sentinel data in human health decision-making despite animals having served as sentinels for environmental risks to people. Because human and financial resources are becoming more and more limited, strategic decisions need to be made on how to best allocate surveillance resources. To date, most wildlife surveillance has been opportunistic. Even targeted surveys are often based on sampling wildlife caught for other purposes or those populations that are easily and safely accessed for testing. Risk-based surveillance is being advocated for hazard selection, as well as to identify the population strata and targeted sample sizes required to meet objectives (Stark et al. 2006).

Surveillance able to provide signals of population vulnerability in advance of harm requires attention be paid not only to sub-populations of wildlife most likely to yield hazards of concern but also to analyzing the pathways to emergence or transmission of pathogens by taking a health intelligence approach that considers social, behavioural, ecological and health data (Daszak 2009). Risk-based surveillance should be promoted to target resources to areas and populations that will be most informative. Emphasis should be placed on focussed surveillance at spatial interfaces of different climatic conditions to track changes in transmission systems; document range expansion of vectors, vector-borne diseases (zoonotic and non-zoonotic), food-borne pathogens and aquatic pathogens and identify geographic clusters of mortality from toxins including harmful algae blooms. This information will demonstrate both changes in distribution of known hazards as well as show how climate conditions are affecting the potential for epidemiological change. Selection of which hazards to emphasize should be based on risk assessments that take into account the likelihood of human exposure, possible magnitude of effects in terms of impacts on morbidity, mortality and determinants of health and capacity to mitigate or prevent effects.

The rate of pathogen discovery has accelerated with the advent of more advanced molecular and genomic diagnostic methods. Strategically placing new capacity or enhancing current capacity in locations with different climatic conditions would focus surveillance efforts at forefront of possible climate-driven epidemiological changes. However, reliance on these methods of hazard detection alone is insufficient to prioritize risk and make strategic resource allocation decisions.

2.2.4 Biological sentinel scenario: there is uncertainty if a hazard in a viable exposure pathway is capable of causing harm

In this scenario, either a suspected hazard is present in the environment but there is insufficient evidence of effect to warrant risk reduction actions or there are newly introduced or previously unknown agents in the environment, the effects of which are unknown. The role for wildlife health programs in this case is to link the presence of the hazard with a biological effect to inform recognition of a risk and help prioritize risks requiring further assessment or management.

Associating pathological effects in wildlife with a newly discovered pathogen can reduce the likelihood of spurious claims of emerging public health risks (Lipkin 2013). General scanning surveillance can link the detection of a new infectious or parasitic agent with pathological effects, helping in risk prioritization for further investigation. It can also link environmental distributions of toxins/pollutants with biological effects, assisting in risk assessment. Bio-sentinel efforts should ensure capacity to follow-up unusual cases of morbidity and mortality with pathological examination at locations experiencing extreme or unusual weather to assist in documenting climate-associated effects on newly introduced hazards. With accompanying capacity for risk assessment and communication, the resulting knowledge can be properly placed within a public health context.

2.2.5 Surprise scenario: the managers want to be prepared for unanticipated effects

This is the scenario intended to create alerts of unanticipated effects. The combination of approaches described in the preceding scenarios serves to enhance analytical capacity to integrate multiple streams of evidence through a health intelligence system to reduce surprise from unexpected impacts of climate change. Understanding the eco-epidemiological system, as well as the social framework and underlying risk perceptions, can help in deciding when and how to act in response to the detection of a parasite or pathogen in wildlife (Jenkins et al. 2015). This includes tracking not just disease incidents or hazards but also the circumstances and situations that promote movements, transmission and establishment of hazards in the environment and subsequent human exposure and impacts.

An evolution of wildlife health programs from the traditional focus on disease surveillance alone to a health intelligence model may improve the ability to detect unanticipated threats and increase the efficiency and value of its information products. Health intelligence is the combination of surveillance and reconnaissance outputs with additional contextual information to provide early warning of emerging threats (Demirtas et al. 2014). Surveillance refers to general scanning surveillance in populations and locations of interest; reconnaissance refers to targeted information acquired on specific issues in the populations of interest. Health intelligence works best when it is designed based on strategies and objectives rather than focussed on producing outputs for known or fixed targets, like specific diseases (Brown 2014). Just as the war on terrorism required military intelligence to shift to more dynamic intelligence models, climate change is driving public health surveillance to be more flexible and adaptable to changing and unexpected conditions. Epidemic intelligence similarly collects information on incidents of diseases (through traditional surveillance and reconnaissance) as well as event-based components (unstructured data gathered from online sources, citizen science, scientific literature and intersectoral and international communications) to provide additional indicator signals and context to inform risk assessment (Paquet et al. 2006). The Canadian Wildlife

Health Cooperative provides wildlife health intelligence for Canada, but its scope of practice is limited due to constraints on resources and capacities. This creates gaps in ability to anticipate unforeseen events and provide early warning of emerging threats.

There is growing recognition that the response to infectious diseases is typically reactive and too late. Public health leaders are promoting a shift in emphasis from detection and outbreak response to prevention of infections at source. The Public Health Agency of Canada is seeking new or enhanced methods to better detect, assess and respond to vector-, water- and food-borne diseases by integrating animal, human and ecosystem health. Wildlife connects the environment with community and public health to improve local anticipation and preparedness for endemic and emerging diseases. Wildlife health intelligence can inspire early action to reduce human exposure to environmental pathogens and parasites.

The emergence of public health threats due to climate change will be associated with interconnected economic, social and environmental changes. Understanding these changes is crucial for preparedness and subsequent prevention and control actions. New tools for surveillance are being promoted to collect and assess information for rapidly responding to changing risks and to anticipate drivers of emergence of new threats (Brookes et al. 2015). Transparent and repeatable methods are needed to identify and prioritize threats and make recommendations on higher risk situations and settings to target resources.

2.3 Opportunities, gaps and challenges

There is substantial evidence to support claims that a systematic wildlife health intelligence system can establish the environmental distribution and human exposure potential to infectious and non-infectious environmental hazards and that these signals can inspire public and regulatory response to reduce exposures and harms from these hazards. Wildlife disease provides understandable biological evidence of the effects of an environmental hazard, helping in risk assessment and risk communication that can inspire risk reduction changes in advance of human harm. Targeted survey or surveillance of known hazards, especially at the borders of climate conditions or ecozones, could help to establish changes in human exposure risks associated with climate change in advance of clues seen in human health outcomes.

The primary obstacle to nominating specific wildlife health indicators for climate change adaptation for public health is the lack of an evidence base to nominate the ‘best’ (most cost-effective, reliable, understandable and predictive) early warning signals based on specific pathologies or etiologies. This includes lack of understanding of where to look, when and in which species. A hazard-based strategy (that allocates surveillance resources based on known hazards) is limited to a sub-set of concerns and does not adequately address the needs for emerging or unknown threat detection, cumulative effects assessment, or tracking the positive contributions of wildlife to community coping. There has been inadequate attention to the development of threat assessment frameworks that can establish the general and specific relationship between environmental change and public health outcomes (e.g. Eisenberg et al. 2007). For wildlife disease, the legislative approach that emphasizes detection of pathogens of regulatory concern has resulted in programs wherein pathogen detection was sufficient as an outcome, with little investment in capacity to assess its significance from a health impact perspective. Concepts of health intelligence for climate change threat assessment are lacking in wildlife health. This capacity is not currently funded in Canada. This is not to be unexpected given that there remains an ongoing debate about how to undertake climate change vulnerability assessments in general (Füssel and Klein 2006).

Canada's current wildlife health program is limited in its capacity to contribute to climate change early warning for a number of reasons. Geographic coverage and reliance on opportunistic sampling limits the amount of Canada that can be covered by surveillance and prevents strategic allocation of resources at most vulnerable locations or populations. Wildlife health surveillance for public health remains limited largely to tracking known pathogens. Adopting new concepts of risk-based surveillance and health intelligence can improve the utility of wildlife signals for public health. It can also reduce reliance on expert opinion to select the best populations and hazards to target for climate change adaptation purposes. Greater challenges will be met trying to integrate wildlife information into community adaptation planning based on augmenting and protecting social determinants of health derived from wildlife.

3 Conclusions

There is a theoretical basis, growing opinion and numerous examples of how wildlife can help to inform public health decisions on climate change risk management. What is lacking is a systematic way to collect, integrate and communicate the direct and indirect effects of climate change on wildlife health for public health purposes. A wildlife health intelligence system could collect both data on incidents of disease and hazard discovery as well as information on social and environmental conditions that affect risk perception and likelihoods of human exposure or harms to help prioritize risk communications and strategic management decisions.

Acknowledgements This work was funded in part by the Public Health Agency of Canada.

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