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PERSPECTIVE

Oceans and human health—navigating changes on Canada's coasts

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Abstract

Ocean conditions can affect human health in a variety of ways that are often overlooked and unappreciated. Oceans adjacent to Canada are affected by many anthropogenic stressors, with implications for human health and well-being. Climate change further escalates these pressures and can expose coastal populations to unique health hazards and distressing conditions. However, current research efforts, education or training curriculums, and policies in Canada critically lack explicit consideration of these ocean–public health linkages. The objective of this paper is to present multiple disciplinary perspectives from academics and health practitioners to inform the development of future directions for research, capacity development, and policy and practice at the interface of oceans and human health in Canada. We synthesize major ocean and human health linkages in Canada, and identify climate-sensitive drivers of change, drawing attention to unique considerations in Canada. To support effective, sustained, and equitable collaborations at the nexus of oceans and human health, we recommend the need for progress in three critical areas: (*i*) holistic worldviews and perspectives,

(*ii*) capacity development, and (*iii*) structural supports. Canada can play a key role in supporting the global community in addressing the health challenges of climate and ocean changes.

Key words: oceans, coastal, oceans and human health, environmental health, coastal communities

Introduction

For millennia, the benefits and hazards of the ocean (here defined to include marine and coastal environments) have been embedded in the diverse material lives, identities, knowledge systems, and cultural practices of coastal populations around the world (Tran et al. 2008; Jackley et al. 2016; Chinain et al. 2019). However, the magnitude and scale of anthropogenic impacts to the world's ocean (e.g., overfishing, habitat and biodiversity loss, coastal degradation, and pollution), including climate change (e.g., sea level rise, ocean acidification, and increased frequency and intensity of extreme weather events), are unprecedented and have profound repercussions for human health (Pörtner et al. 2019). Coastal communities, health practitioners, and policy makers are thus increasingly challenged to respond to the health and livelihood impacts of climate and ocean change (Vogel 2019). To do so effectively, they require dedicated knowledge and skills, and a strong supporting evidence base from which to anticipate, prepare, and build effective policies and practices.

Important links between oceans and human health are increasingly recognized by the scientific community (National Research Council 1999). Understanding these linkages requires holistic frameworks capable of integrating information derived from diverse intellectual traditions and epistemologies, fields of scientific inquiry, approaches, and methods (Allen 2011; Depledge et al. 2019; Meredith et al. 2019). Such methods must also accommodate for the dynamic, multisectoral interactions, and causal interconnections, at various level of biological (i.e., "from genes to ecosystems") and social (e.g., community, region, international) organization.

The metadiscipline of oceans and human health

Responding to this complexity, dedicated initiatives in the United States and Europe have focused directly on the nexus of oceans and human health for several years (National Research Council 1999; Moore et al. 2013a; Sandifer et al. 2013). These initiatives have included concerted research and training programs and centers, seminal publications, and knowledge-sharing events (symposia, workshops, and meetings), among others (**Fig. 1**). Collectively, this has led to the emergence of a distinct "metadiscipline" referred to as "oceans and human health" (OHH) (Sandifer et al. 2013). The OHH metadiscipline has provided an overarching framework for "adopting and incorporating knowledge across many fields of study" (Mihelcic et al. 2003, p. 5317) and for enhancing connectivity, collaboration, and coordination across diverse agencies and institutions involved in oceans and human health. Ultimately, this has yielded richer insights and perspectives into the multiple ways in which the ocean affects human health and has contributed to training a new generation of interdisciplinary scientists (Laws et al. 2008; Sandifer et al. 2013). These developments parallel those of other systems-based environmental-health paradigms (e.g., EcoHealth, OneHealth, Planetary Health), which have emerged in the last few decades to promote collaboration between disciplines and all relevant sectors.

No dedicated OHH initiatives exist in Canada

While not explicitly self-presented under the terms of OHH, scientists in Canada have, in collaboration with Indigenous communities, made important contributions at an international scale to understanding diverse health-related dimensions (nutritional, toxicological, cultural) of marine-based diets (see, for example Innis et al. 1988; Kuhnlein et al. 1991). In some cases, they have also made direct contributions to the development of the OHH metadiscipline (see for example Dewailly et al. 2002).

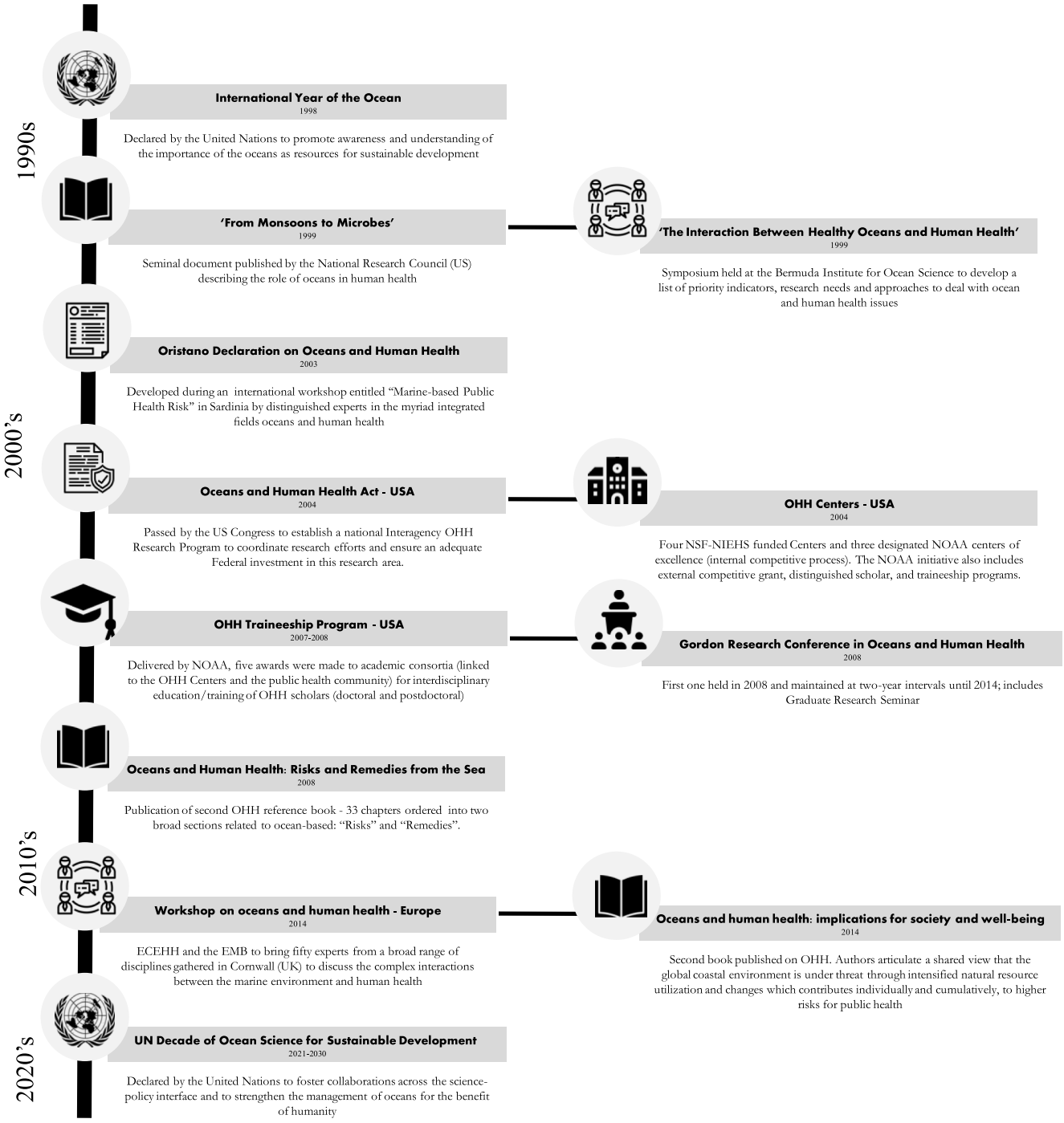

Fig. 1. Synthesis of selected initiatives that have contributed substantially to the development of the metadiscipline of OHH. This is not intended to be exhaustive or comprehensive; the reader may refer to other authors for a more complete narrative of field developments in OHH (Sandifer et al. 2013). Adapted from Tyson et al. (2004), Depledge et al. (2013), and Sandifer et al. (2013). ECEHH, European Centre for Environment and Human Health; EMB, European Marine Board; NIEHS, National Institute of Environmental Health Science; NOAA, National Oceanic and Atmospheric Administration; NSF, National Science Foundation; OHH, Oceans and Human Health.

Despite this, to date, Canada has largely failed to promote an integrated interdisciplinary and collaborative research and policy effort in this area. Meanwhile, national reports on climate change impacts to marine environments (Greenan et al. 2019), and human health (Berry et al. 2014), respectively, have highlighted several human health issues (e.g., exposure to natural hazards, the contamination of food, water, and air) that can materialize through ocean pathways, and which can disproportionately impact coastal populations. It is not surprising therefore, that the national Expert Panel on Climate Change Risks and Adaptation Potential identified coastal communities, northern communities, human health and wellness, ecosystems, fisheries, and physical infrastructure, as the top six areas of climate change risk facing Canada (Council of Canadian Academies 2019). Given the common climate-related risk factors between the health of the ocean and the health of people, there is a need for a consolidated and climate-sensitive approach to foster sustainable oceans and healthy coastal communities in Canada.

By adopting the *Oceans Act* in 1996–1997, Canada was historically a global leader in recognizing the need for comprehensive oceans management legislation (Jessen 2011). However, progress in implementing the Act over the last 20 years has been deemed "modest and slow" (Jessen 2011), leading some to question whether Canada is a "follower" rather than a global leader (Ricketts and Hildebrand 2011). The Council of Canadian Academies (2013) reported that Canada ranks among the top countries in output and impact of ocean science papers, but ocean science is losing ground relative to other fields faster in Canada than in other countries. The 1998 United Nations (UN) International Year of the Ocean catalyzed significant OHH activities (Sandifer et al. 2013) (**Fig. 1**). With the 2021–2030 UN Decade of Ocean Science for Sustainable Development (to which Canada has formally supported its participation (DFO 2018a)), slated to begin next year, there is a renewed opportunity to further an OHH research, capacity development, and policy agenda in Canada and, indeed, internationally (Depledge et al. 2019; Fleming et al. 2019; Borja et al. 2020). As Jessen (2011, p. 48) suggested, Canada has "previously demonstrated oceans leadership on the international stage and could do so again".

This paper brings together multiple disciplinary perspectives from academics and health practitioners to articulate a foundation for more holistic and climate-sensitive approaches for understanding and addressing ocean-related health issues in Canada. To this end, we synthesize major ocean and human health linkages in Canada, emphasizing climate-sensitive drivers of change. We draw particular attention to unique issues in Canada and highlight gaps to support effective, sustained, and equitable collaborations at the nexus of oceans and human health. Finally, we recommend approaches and directions in three critical areas to foster more integrated and equitable collaborations, to enhance capacity for practitioners, and for Canada to make contributions on this global challenge.

Important dimensions of oceans and human health in Canada

Canada shares many priority issues highlighted in OHH literature developed in other country contexts; however, three key (in some cases, overlapping) dimensions that characterize many coastal regions and populations in Canada are not extensively discussed explicitly in the OHH literature. These include (*i*) the vast and diverse physical and human geography along the expansive coastline, (*ii*) Indigenous Peoples governance and access to the oceans and marine resources, and (*iii*) the Arctic and sea ice. While these issues are represented in diverse literatures in both Canada and elsewhere (see for example Eythórsson 2003; Loring and Gerlach 2009; and O'Neill 2008), they have not necessarily featured prominently in literature presented under the auspices of the OHH metadiscipline.

Geography

Representing over 16% of the world's coastline, and extending over 7 million km^2, Canada has the longest coastline of any country in the world (Archambault et al. 2010). Bordering three oceans (the Atlantic, Pacific, and Arctic oceans), there is a tremendous diversity of climatic, physical, oceanographic, and biological characteristics across Canada's coastal regions (Archambault et al. 2010). This diversity is reflected in the mosaic of contemporary identities and ways of life among the over seven million people who reside in the traditional fishing communities, remote Indigenous settlements, and large urban centres that dot the coastline (Lemmen et al. 2016). Most of Canada's ocean coastline is undeveloped, remote, and free of industrial activity. However, densely settled coastal areas (and indeed, several major industrial cities connected through the St. Lawrence Seaway) exhibit many of the same anthropogenic pressures that characterize other global regions (Harrison and Parkes 1983; Ricketts and Hildebrand 2011). The paradox of remoteness and major development (Harrison and Parkes 1983), the distinctive geographic features and social factors on each coastline (e.g., strong dependence on marine resource for various facets of life and identity in several small communities, and under resourced public institutions and physical infrastructure) (Dolan and Ommer 2008; Kipp et al. 2019), and the complex legal and jurisdictional landscape (e.g., overlapping authorities and responsibilities among federal, provincial, territorial, and Indigenous governments), renders the development and implementation of national ocean policies and monitoring and management frameworks particularly challenging (McDorman and Chircop 2012).

Indigenous Peoples (First Nations, Inuit, and Métis)

For Indigenous Peoples in Canada (First Nations, Inuit, and Métis)—many of whom reside in coastal areas and depend on marine ecosystems for various facets of life and identity (Cisneros-Montemayor et al. 2016)—access to oceans and marine resources represents a critical dimension of health and well-being (Bennett et al. 2018). The consumption of seafood by coastal Indigenous communities is almost four times higher than the overall Canadian average (Cooke and Murchie 2015). These marine traditional or country foods (which can include seaweed, shellfish, finfish, and marine mammals) contribute importantly to diet quality (Kenny et al. 2018; Marushka et al. 2019) and prevention of noncommunicable diseases (Zhou et al. 2011; Hu et al. 2018, 2019). Furthermore, the harvest and sharing of this food has significant importance for psychosocial dimensions of health and well-being (Pufall et al. 2011). Meanwhile, environmental contaminants (e.g., methylmercury) in marine country foods represent an important public health concern, particularly for Inuit women of childbearing age (Pirkle et al. 2016). Furthermore, some ocean-related health concerns, such as exposure to zoonotic pathogens (e.g., *trichinella* spp., *toxoplasma gondii*, *anisakids*), may be of higher relevance to Indigenous Peoples who may consume wild-harvested seafood raw, without having been subjected to formal food safety testing and regulations and (or) being previously frozen (Goyette et al. 2014). Importantly, these issues must be situated within a culturally relevant framing as Indigenous Peoples in Canada experience significant social and health disparities rooted in European colonization (Adelson 2005; ITK 2018) and enduring structural injustices related to oceans and fisheries management and other environmental and climatic justice issues (McKinley 2007; Tsosie 2007; Whyte 2015; Olive and Rabe 2016). Ocean and fisheries management in Canada has been a site of historical and enduring resistance for many Indigenous Peoples, whose rights, interests, knowledge systems, and perspectives/experience, have often been under-represented and undermined in such processes (Wiber and Milley 2007; King 2011; Lam 2015; Daigle et al. 2016; von der Porten et al. 2019).

The Arctic coastline and sea ice

The Arctic coast represents over 70% of the Canadian coastline. It is one of the regions of the world most impacted by, and ecologically sensitive to, climate change on the planet (IPCC 2019). While climate change poses major challenges to Arctic Indigenous communities, climate-related issues must be contextualized, within broader contemporary and historical social, economic, and health priorities, interests, and needs of local communities (Huntington et al. 2019) that differ considerably from elsewhere in the country (Kenny 2019).

The presence of sea ice is a defining feature of life in the Arctic, shaping geomorphological and ecological processes, affecting transportation access, and providing a substrate for culturally valued and economically important harvesting activities (Gearheard et al. 2013; Huntington et al. 2016). While the importance of sea-ice to human health is not directly featured in international OHH literature, there are several impacts on human health that are directly and indirectly related to sea ice conditions, such as harvester safety and food access (Ford 2009; Council of Canadian Academies 2014; Huntington et al. 2016).

While none of these issues are exclusive to Canada, they have not featured prominently in existing OHH literature, which has been developed largely in countries with high population densities, and intensive anthropogenic pressures in many coastal regions (as in Europe and the United States). Several common OHH issues as those highlighted in international contexts are discussed in the subsequent section.

The nexus of oceans and human health in Canada

In the following section we synthesize several major OHH issues in Canada and discuss climate-sensitive drivers of change. We do so based on seminal OHH publications (namely Walsh et al. 2011; Bowen et al. 2014) and published literature presented in national (Canadian) assessments of climate change impacts to oceans (Greenan et al. 2019), coastal economies (Lemmen et al. 2016), and human health (Séguin 2008; Berry et al. 2014). While this synthesis draws on Canadian assessments, ultimately, there is one Global Ocean. Accordingly, there are strong parallels and relevance to assessments conducted in other country contexts, particularly the United States (Griffis and Howard 2013), with shared ocean basins and political boundaries. International partnerships will be necessary to ensure robust and coordinated monitoring, training and management or adaptation plans, as well as to develop shared priorities at the ocean and human health front.

Synthesis of major ocean and human health issues in Canada

Thousands of coastal towns and communities rely directly upon Canada's ocean resources for food security, recreation and physical activity, culture, employment, and income (including multimillion-dollar marine industries such as fisheries and aquaculture, tourism, transportation, and marine shipping) (Ommer 2007; Dolan and Ommer 2008; Hancock et al. 2016). However, these benefits are not extensively studied from a public health perspective in Canada, and indeed, health benefits from the oceans have traditionally been less emphasized than risks in broader OHH literature.

With the exception of Arctic communities (Rochette and Blanchet 2007; Saudny et al. 2012), to date there has been limited public health research in Canada's coastal regions (Dolan et al. 2005). Nevertheless, priority human health issues highlighted in international literatures (Walsh et al. 2011; Bowen et al. 2014) also exist in Canada. For example, shellfish contamination from harmful algal blooms (HABs) and their biotoxins, including amnesic, diarrhetic, and paralytic shellfish poisonings, have been reported in both Canada's Atlantic and Pacific coasts (Gibbard and Naubert 1948; Acres and Gray 1978; Quilliam et al. 1993; McIntyre and Kosatsky 2013; Taylor et al. 2013;

BCCDC 2020). Meanwhile, contamination of marine-source foods by metals and new persistent organic pollutants (e.g., per- and polyfluorinated compounds) remains a significant and complex public health concern, particularly for Indigenous Peoples in the Arctic (Laird et al. 2013; Pirkle et al. 2016; Adamou et al. 2018; Muir et al. 2019).

Sea change

Although some societal benefits from the oceans are at risk from local stressors, such as pollution and runoff, others are at greater risk from climate-related stressors (Singh et al. 2020). Indeed, several socio-economic sectors in Canada's coastal regions, namely fisheries, tourism, transportation, energy and infrastructure, have been identified as being particularly climate sensitive (Lemmen et al. 2016). Climate-related ocean changes may have repercussions for human health—notably, related to exposure to physical hazards and distressing conditions, extreme weather events, coastal flooding, and declining sea-ice conditions; changing seafood abundance and species compositions; and compromised seafood safety (**Table 1**; **Fig. 2**).

Although one-third of Canada's coastline (including several major Canadian coastal cities (Bush and Lemmen 2019) is deemed to be moderately to highly vulnerable to sea-level rise, the consequences for human health are largely unknown (**Table 1**; **Fig. 2**). In the Arctic, sea ice extent, thickness, and duration are declining rapidly, leading to less predictable and safe navigation for harvesters, whose physical safety, food security, and psychosocial dimensions of health have already been impacted (Ford 2009; Council of Canadian Academies 2014). Although opportunities for increased Arctic shipping are often evoked in discussions of receding sea ice (Melia et al. 2016), in the short-term, these changes can also disrupt marine transport of essential items (e.g., nonperishable foods, building materials, heating fuel) to remote communities that lack road access (**Table 1**).

Collectively changes to ocean physicochemical and biological properties may provoke increases in the occurrence and proliferation of seafood safety hazards, such as HABs and pathogenic microorganisms, with consequences for human exposures (**Table 1**). Warming ocean conditions (as well as thawing ice and permafrost) could also lead to the mobilisation of chemical contaminants in sedimentary matrices (Yang et al. 2016; Waits et al. 2018). It can also alter rates of elemental mercury methylation (limiting factor for further methylmercury bioaccumulation and biomagnification) and drive shifts in ecological relationships, which may lead to novel pathways of contaminant bioamplification in marine food webs (Alava et al. 2017). Climate change is already driving species' ranges poleward or following environmental temperature gradients (Cheung et al. 2013; Pinsky et al. 2013) and is projected to alter the biomass and productivity of fished stocks, with increased productivity in temperate and polar regions under climate change (Cheung et al. 2016; Lotze et al. 2019). In addition, extreme events, such as marine heatwaves, are already affecting marine ecosystems and fisheries, with large impacts that are exemplified by the 2015–2017 marine heatwaves in the Pacific coast of Canada (Cavole et al. 2016). These events are projected to re-occur in the coming decades with increasing intensity of impacts on fish stocks and fisheries (Cheung and Frölicher 2020). In general, fisheries' productivity in Canada is projected to increase as oceans warm with climate change (IPCC 2019; Lotze et al. 2019). While rising international prices for many seafood products harvested in Canada remain an incentive to export, rather than develop domestic markets (DFO 2018b), locally harvested seafood plays—and has historically played—a central role in the food security and sovereignty, culture, history, arts, culinary patrimony and practices, recreational activities, intergenerational knowledge transmission, and vitality of coastal communities across Canada. Thus, changes in the distribution and abundance of culturally valued seafood species may have negative impacts on community food security and nutritional health, including among Indigenous Peoples (Marushka et al. 2019). The emergence of new commercial fisheries may lead to complex interactions between

Table 1. Summary of major climate change impacts to oceans in Canada[a] and potential consequences for human health.

Climate and oceans						Consequences for human health	
			Regional variability and seasonal considerations across Canada				
Ocean conditions		Climate-related changes	Arctic	Atlantic	Pacific	Potential direct and indirect examples of impacts to human health	Examples
Weather	Coastal weather	Frequency and intensity of extreme weather events	↑	↑	↑	• Collectively, stronger storm surges, sea level rise, and declining sea-ice can increase the risks of flooding and erosion and many coastal communities	• Canadian cities such as Vancouver and Richmond (BC), Charlottetown (PEI), and Tuktoyaktuk (NWT) are at risk of serious inundation (Ricketts and Hildebrand 2011).
	Marine winds, storms and waves	Wave activity/ height/season duration (related to sea-ice extent/ duration)	↑	↑	↑ winter; ↓ summer	• Coastline erosion, flooding, and infrastructure damage may disrupt coastal recreation and physical activity	
Physical ocean properties	Relative sea level	Increasing or decreasing depending on vertical land motion	Beaufort Sea	Most of Atlantic	Most of Pacific	• Damage to coastal infrastructure (e.g., ports, water, housing), and ecosystems and public/private spaces, and infrastructure can result in displacements, evacuations, economic losses, disruptions to daily life and essential services, as well as livelihoods and social interactions	
	Extreme water levels	Magnitude and frequency (where/when there is open water)	↑ summer and fall	↑ winter and spring	—	• Collectively, such changes may lead to evacations, displacement and other disruptions to daily life, including, travel, livelihoods, and coastal economies • In all cases, these changes may lead to increased risks of drowning, physical injuries, reduced recreation, and impacts to psychosocial health and social determinants of health	
	Sea ice	Continued reduction, perennial sea ice replaced by thinner seasonal ice	↓	—	Arctic (summer), Atlantic (winter)	• Sea ice decline may lead to less predictable and safe sea-ice travel and marine navigation (particularly in the Arctic) • Sea ice recession may introduce new economic opportunities, such as increased marine shipping and tourism (e.g., cruise ships), but may also present hazards (perennial ice shifting) for marine navigation	• Inuit harvester safety has already been impacted and has had repercussions for food security (Ford 2009; Council of Canadian Academies 2014) • In 2018, annual barge service carrying hundreds of tonnes of cargo to the western Arctic was cancelled due to impassable ice in the Amundsen Gulf, leaving store shelves bare, while food prices, already high, were reported by residents to have climbed further (Pruys 2018)

(*continued*)

Table 1. (*continued*)

Climate and oceans						Consequences for human health	
			Regional variability and seasonal considerations across Canada				
Ocean conditions		Climate-related changes	Arctic	Atlantic	Pacific	Potential direct and indirect examples of impacts to human health	Examples
Physical and biochemical	Ocean temperature	Widespread warming of the upper oceans	↑ summer (ice-free areas)	↑ summer and winter	↑ Northwest Pacific (winter)	• Changes to the occurrence, distribution, and accumulation of biological and hazards in coastal air/water and seafood as well as changes in seafood quality (nutritional composition)	• Increased surface temperatures and storminess are significant factors stimulating red tide and other harmful algal blooms responsible for marine toxins production in Canada (Mudie et al. 2002)
	Ocean acidity	Widespread increase in acidity of the upper oceans	↑ occurring most rapidly	↑	↑	• The contamination of coastal environments and marine resources may have acute and long-term impacts to coastal economies (e.g., beach use and tourism) and livelihoods (e.g., bivalve fisheries)	• *Clostridium botulinum* spores and toxins, are produced at temperatures above 4 °C and may increase rates of food-borne botulism among Arctic communities who rely on traditional preservation methods for marine mammals (Parkinson and Evengård 2009)
	Subsurface oxygen	Decreased and low subsurface oxygen conditions	More widespread	More widespread	Particularly in the Northwest Pacific	• Changing biophysical ocean conditions will alter the habitable range of marine species, while changing ocean acidity will affect their reproductive success with consequences for food availability and coastal economies (see "Species and ecological")	• *Vibrio* spp. are naturally occurring bacterium present in seawater, which can accumulate in shellfish through phytoplankton, zooplankton, and copepod vectors when seawater temperatures become warmer. When shellfish contaminated with pathogenic *Vibrio* spp. are consumed raw or undercooked, foodborne illness can result (Smith and Fazil 2019). *Vibrio* infections are projected to become more frequent, and found in a wider range of places, including where they were previously nonendemic with warming waters (King et al. 2019).
	Nutrient supply	Changing	No long-term data	No consistent pattern	↓		• A recent model estimated a 56% increase in tissue MeHg concentrations in Atlantic bluefin tuna (*Thunnus thynnus*) due to increases in seawater temperature between 1969 and 2017 (Schartup et al. 2019).

(*continued*)

Table 1. (*concluded*)

Climate and oceans						Consequences for human health	
			Regional variability and seasonal considerations across Canada				
Ocean conditions		Climate-related changes	Arctic	Atlantic	Pacific	Potential direct and indirect examples of impacts to human health	Examples
Species and ecological	Species abundance and distribution	Changing	Poleward shifts for many species; increase in ecological productivity in temperate and polar regions			• Changes in species distribution/ abundance could promote the development of emerging commercial fisheries, but may interact with subsistence users, or historically fished and culturally and economically important species with consequences to food security, nutritional health, cultural wellbeing. and psychosocial dimensions of health	• Individual species respond differentially to warming waters, and the introduction of new species to ecosystem can result in novel ecosystems that can lead to changes in marine biodiversity and abundances of traditionally fished and culturally and economically important species (Pinsky et al. 2013; IPCC 2019; Lotze et al. 2019), such as salmon (to fisheries and First Nations in British Columbia) (Weatherdon et al. 2016) and lobster (in the Atlantic) (DFO 2019b) • Declines in salmon and herring catch may lead to inadequate intakes of several vitamins, minerals, protein and eicosapentaenoic acid (EPA)/ docosahexaenoic acid (DHA) for coastal British Columbia First Nations (Marushka et al. 2019)

[a]Conclusions are synthesized from Greenan et al. (2019) for ocean physio-chemical and ecological and Lemmen et al. (2016) for marine-based economic sectors.

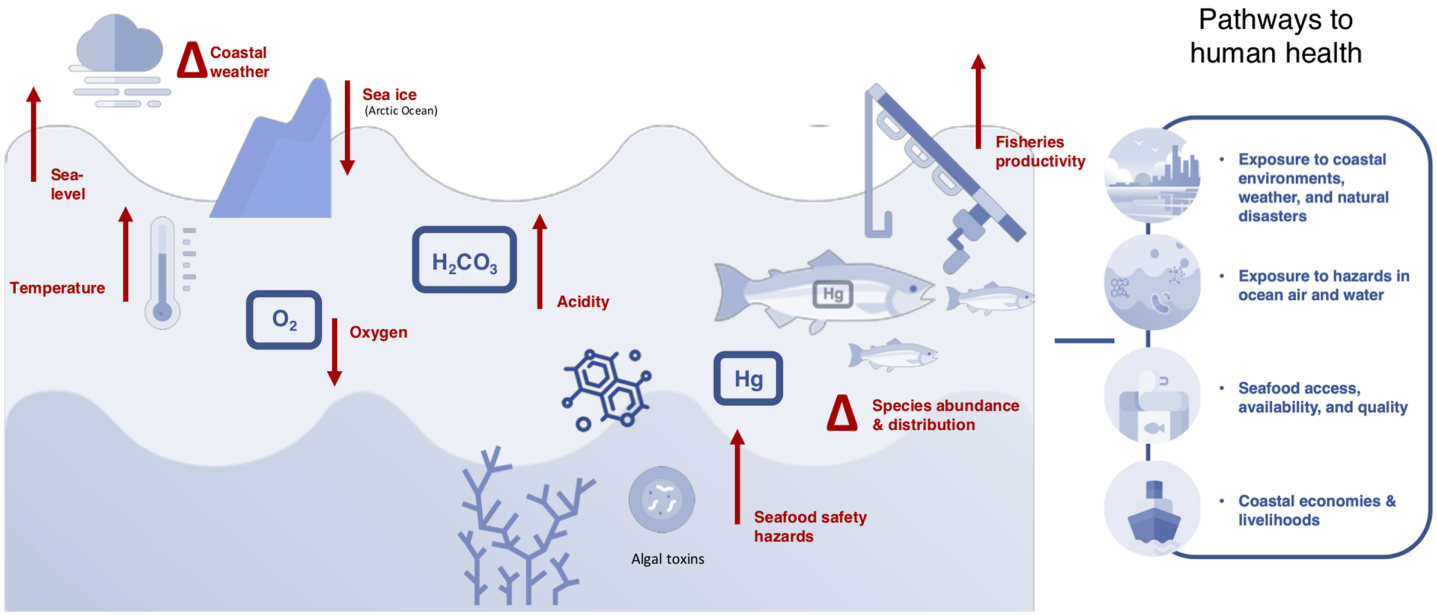

Fig. 2. Summary of major climate change impacts to oceans adjacent to Canada and potential consequences for human health. Climate-related physicochemical changes in oceans surrounding Canada include warming surface temperature, acidification, decreasing subsurface oxygen concentrations and the creation of hypoxic zones. Climate-related changes to oceans' physicochemical properties have repercussions for the vertical transport of carbon and nutrients as well as the biogeochemical properties of marine waters, marine microflora, primary productivity, trophic dynamics, and species distributions (Cheung et al. 2009; Hoegh-Guldberg and Bruno 2010; IPCC 2019). Changes in ocean temperature and oxygen levels will alter the habitable range of marine species, while changing ocean acidity will affect their reproductive success with consequences for food availability and coastal economies (IPCC 2019). Oceans are interconnected through circulation patterns and share several common climate-related changes, despite differences in physicochemical properties and hydrology. Regional differences are highlighted in **Table 1**.

commercial and subsistence dimensions of marine harvests (Islam and Berkes 2016), particularly among Indigenous Peoples (Powell 2012; von der Porten et al. 2019).

An integrated Canadian framework

To anticipate and proactively respond to emerging public health threats from the oceans, as well as to better understand, account for, and ensure the sustainable continuity of human health benefits from oceans, there is an urgent need to develop holistic approaches for integrated research, policies, and education and training curriculums across Canada. To support conditions for effective, sustained, and equitable collaborations across relevant sectors and interests, we propose an integrated framework (**Fig. 3**) that includes three key dimensions, namely: (*i*) holistic worldviews and perspectives, (*ii*) capacity development opportunities, and (*iii*) dedicated structural supports (e.g., funding and resources, leadership) (Bowen and Ebi 2015; Meissner 2018; Cooke et al. 2020). These are discussed in further detail below.

Holistic worldviews and perspectives

Confront biases

Overcoming inherent researcher subjectivity and disciplinary or field biases should be seen as paramount to the conduct of research (Buse et al. 2018). Ocean governance, policy, and discourse have long been dominated by empirical data, predictions, assumptions, and other paradigms of the natural marine sciences (Tyson et al. 2004; Macdonald 2018). Similarly, the OHH literature has

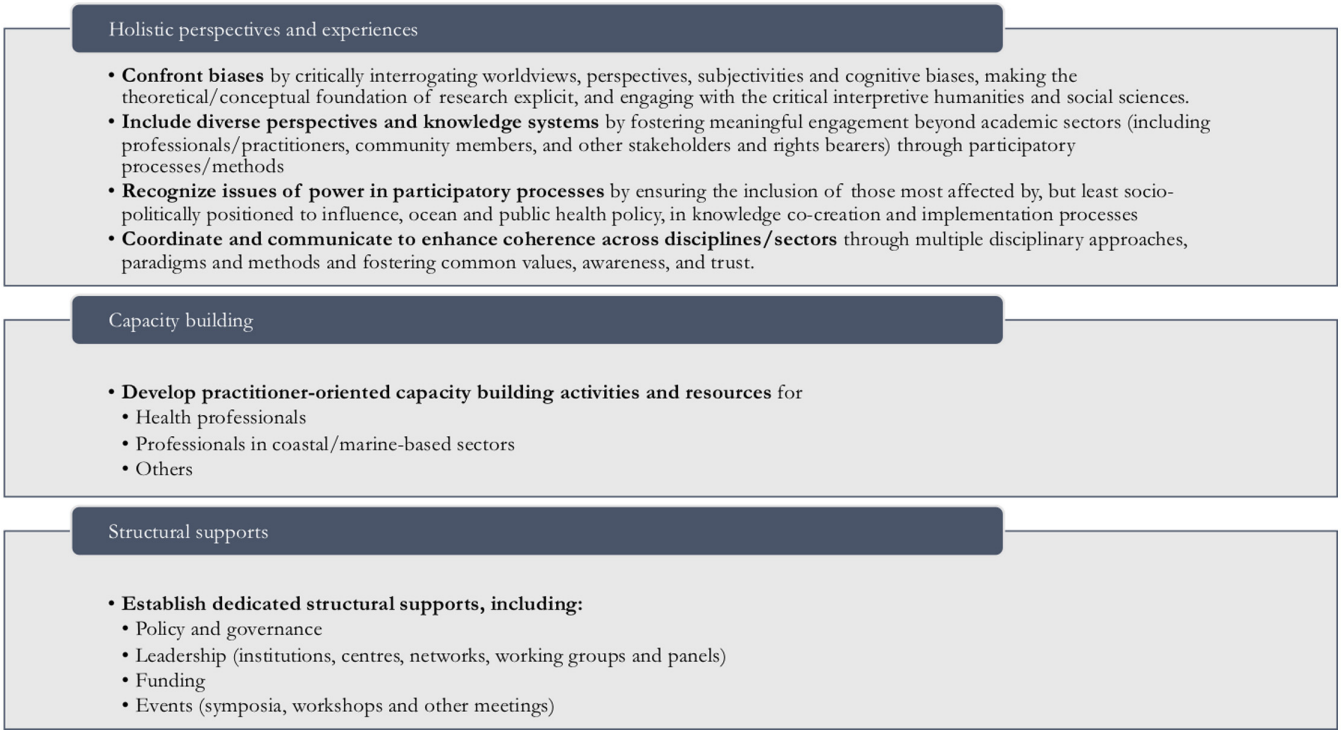

Fig. 3. Information derived from diverse perspectives (e.g., general public, policy makers), intellectual traditions and epistemologies, fields of scientific inquiry, approaches, and methods (e.g., empirical field/observational research, laboratory experiments, computational models, epidemiological modelling, clinical research, participatory and community-engaged research, analysis). Inference techniques can be highly complementary in yielding insights at the nexus of oceans and human health. Ensuring sustained collaboration and coordination, however, requires three key dimensions, namely—holistic worldviews and perspectives, dedicated capacity building opportunities, and structural supports.

traditionally emphasized biomedical issues and bioanalytical approaches from the toxicological, nutritional, and epidemiological sciences (Dewailly et al. 2002; Knap et al. 2002), whereas more broadly, interdisciplinary environmental health research in Canada has been dominated by quantitative studies in which physical health outcomes are emphasized (Masuda et al. 2008). Although such empirical positivist research often does not explicitly refer to a theoretical or conceptual foundation or framing, and the researchers conducting the analysis often assume a "value-free" research orientation (Masuda et al. 2008), values and assumptions that can be traced to renaissance Europe are often nevertheless embedded in the entire research process (Krieger 2011; Rigg and Mason 2018; Soto and Sonnenschein 2018). The choice of theory, method, and engagement (i.e., the framing) determines which conceptualizations, causal interpretations, moral evaluations and (or) treatment recommendations arise among a multiplicity of potential perspectives. Consequently, the framing determines which questions are asked, how knowledge is produced, and how issues are interpreted, prioritized, moralized, and responded to (Entman 1993; Chong and Druckman 2007).

Representing complex phenomena, such as climate change and human health, using simplified physical representations (e.g., "climate reductionism" (Rigg and Mason 2018) and "biomedical reductionism" (Soto and Sonnenschein 2018)), conceals the societal (e.g., political, socio-economic, cultural, historical) dimensions embedded in such processes. Such reductionist approaches also restrict the evidence base and consequently the way in which issues are responded to

(Krieger et al. 2012; Soto and Sonnenschein 2018; Planque et al. 2019). Results predicated exclusively on quantitative physical data are likely to engender policies and initiatives that reflect such approaches. Relatedly, singular and decontextualized focuses on climate change (which pervade much existing environmental literature) can distract and disorient research away from more pressing underlying issues and from actions that can be taken now to improve the lives of local communities (Huntington et al. 2019).

The epistemological, methodological, and political factors that influence inquiry, and researchers' and practitioners' worldviews and perspectives, are thus worthy of being made explicit, and critically interrogated through insights from the interpretative humanities and social sciences (Krieger 2011). Indeed, there is a need to bridge the "significant fissure between studies that apply positivist epistemologies and quantitative methodologies, and those that deploy constructivist/critical research and qualitative methods" (Masuda et al. 2008, p. 446).

Include diverse perspective and knowledge systems

Although ocean-related policy in Canada has traditionally emphasized knowledge derived from the natural sciences, in the public narrative equal importance is given to other forms of knowledge, including local and Indigenous Knowledge (Macdonald 2018). Inadequate links between researchers and policy makers, and the lack of participatory mechanisms are highlighted among issues that have hindered integrated approaches to ocean governance in Canada (Sander 2018).

Meaningful engagement beyond academic sectors at various scales (e.g., community leaders, civic institutions, policy makers, health practitioners, industries, and others) is needed to: identify, and derive deeper understanding of, the priority health issues facing local populations; communicate risks in culturally safe and locally relevant manners; and ensure actions developed (policy, programming, and recommendations) are tailored to local contexts and people's lived experiences (Rigg and Mason 2018; Meredith et al. 2019). Several frameworks and examples of participatory approaches to support knowledge co-production and weaving or braiding together Indigenous and western knowledge are reported in the literature (Bartlett et al. 2012; Plante et al. 2016). Participatory modelling and scenario-based approaches, for example, provide opportunities to include local and Indigenous knowledge in risk assessment and adaptation planning and present the opportunity to derive more holistic causal hypotheses regarding the direct and indirect links between oceans and human health (IPBES 2016; Kenny 2019).

Recognize issues of power in participatory processes

Although participatory processes hold the prospect of enhancing the inclusion of diverse knowledge systems and perspectives, as Berkes et al. (2001, p. 466) noted, there are "formidable problems of inequity and power relationships in using the two kinds of knowledge together". Complex power relations and issues of equity (e.g., asymmetries in impacts experienced versus involvement in decision-making) are embedded in systems of environmental governance and conservation (Masuda et al. 2008; Gill et al. 2019). Consequently, poorly designed engagement processes, structural barriers to participation (e.g., inadequate funding, technological and logistical barriers), and past conflicts and antagonism, may lead to the exclusion of particular stakeholder and right-bearing, groups (Alexander and Haward 2019).

Notably, there is a need to ensure the inclusion of those most affected by, but least socio-politically positioned to influence, ocean and public health policy in knowledge co-creation processes (i.e., procedural and distributive justice) (Minkler et al. 2006; Schlosberg 2007). As Indigenous Peoples take steps to improve wellness through the revitalization and resurgence of traditional food and medicine and ocean and fisheries stewardship systems (Coté 2016; Beveridge 2019),

processes that affirm Indigenous participation and rights may support broader reconciliation. To build a respectful dialogue, such processes must include methodologies (notably, as relevant for Indigenous Peoples, decolonizing methodologies—see for example (Smith 2013; Braun et al. 2014)) and equitable research partnership (e.g., empowering community members as co-researchers) that explicitly recognize, and actively work to counter, the ways in which institutional, situational, and dispositional factors have silenced certain voices and viewpoints and have served to further marginalize and disempower. Practices such as storytelling and art, for example, may provide a basis for individuals and communities to express and validate experiences and epistemologies, while nurturing relationships and knowledge sharing (Dolan and Ommer 2008; Lewis 2011; Rathwell and Armitage 2016).

Coordinate and communicate to enhance coherence across disciplines and sectors

Multiple disciplinarity (i.e., inter-, multi-, post-, and transdisciplinarity) is essential for understanding and addressing complex issues at the interface of oceans and human health. Multiple disciplinarity benefits from several opportunities, including: increased awareness and access to a spectrum of tools, approaches, concepts and methods; deeper and broader understanding of issues; greater potential for knowledge mobilization that ensures that the public are more likely to benefit from it (Cooke et al. 2020). Although diverse methods, systems of knowledge, and fields of inquiry can be highly complementary in yielding insights into the human health impacts of ocean change, practically research on climate, oceans, and human health includes relevant information that is vast, fragmented, and articulated at different levels of spatial and temporal resolution (Carpenter et al. 2009). For example, epidemiologic studies that document consumption of marine-source foods may not describe such foods at the appropriate biological resolution (i.e., generically at the genus level) to be related to marine species research (Rapinski et al. 2018). Meanwhile, quantitative marine harvest and dietary studies may overlook culturally important species that comprise a small fraction of the total harvest and diet—such as small marine organisms (e.g., molluscs, crustaceans, echinoderms, shellfish and algae)—but occupy a vital cultural role, as understood by local and Indigenous knowledge, and as documented in Traditional Knowledge, ethnographics, and social science studies (Rapinski et al. 2018). Research from various fields must therefore be collected, interpreted, analysed, and presented in ways that are accessible and complimentary among fields of inquiry and among researchers, practitioners, and the public. This includes compatible units of measurement and resolution (e.g., spatiotemporal, biological organization/species description, analytical methods). Interdisciplinary fields of inquiry, such as ethnobiology, can occupy an instrumental role in bridging disparate fields of inquiry such as biodiversity conservation and human nutrition and toxicology (Kuhnlein 2014; Caron-Beaudoin and Armstrong 2019). To support information-sharing and to enhance the coherence of methodological approaches and policy response there is a need to familiarize diverse actors with concepts spanning all relevant fields of inquiry and practice, while minimizing disciplinary jargon. This requires improved communication and training, as well as common values, awareness, and trust among historically fragmented groups, disciplines, and sectors (Wilcox et al. 2019) and may necessitate dedicated co-ordinating structures which operate across sectors (discussed further below).

Capacity building opportunities and resources

The development of evidence-based initiatives that address the diverse human health issues within the complexity of ocean systems, necessitates dedicated knowledge, skills, and competencies across the natural, social, and health sciences (Yassi et al. 2019). This requires specific resources and opportunities for training (i.e., the development of knowledge and skills relevant to a specific form of employment) and capacity building (i.e., the process of improving the knowledge base and competencies, as well as changing attitudes and behaviours to implement decisions and perform functions in a more

effective, efficient, and sustainable manner) (Lafontaine 2009; Le Tissier and Hills 2010) in oceans and human health at individual, organizational, and systemic levels (Sandifer et al. 2007; Kite-Powell et al. 2008).

Practitioner-oriented capacity building—health sector

Professionals working in the health sector (which includes health care, public and environmental health, and other allied health services) have an instrumental role in addressing and mitigating acute (e.g., HABs, storms, heat stress) and chronic (e.g., longer-term health and psychological issue) health issues related to changing oceans and climate. Medical professionals in Canada have articulated a strong and coherent voice on capacity enhancement requirements to address ocean and climate change issues (Guitton and Poitras 2017; Veidis et al. 2019) (**Box 1**).

In Canada, public health care and education are delivered by the local health authorities. While many health authorities are currently undertaking activities to respond to the health effects of climate change, they often lack the capacity to work with other sectors to develop climate change adaptation plans for the health of the communities they serve. Increasing the role of the public health sector, particularly in coastal regions, in climate-related ocean and human health issues could help reframe and broaden understanding of climate change from an "environmental issue", to one that also deeply concerns "human health" (Martiquet 2019). Core competencies and training for public health professionals represent an important opportunity to integrate climate change considerations into public health training and practice. Conceptually, the public health disciplines are well-suited to action on climate change because of their interdisciplinary nature and commitment to equity and social justice. However, competencies related to the ecological determinants of health (such as climate change) (Hancock et al. 2016) are absent from the list of Core Competencies established by the Public Health Agency of Canada—a driving force for the design of education program curricula and the evolution of accreditation standards across Canada (PHAC 2008). As such, it is timely to consider how the existing competencies can be improved to better support ecological determinants of health and identify additional competencies that would further enhance and support Canadian public health training and practice in the context of climate and ocean changes. Relatedly, there is also a need to systematically evaluate policies and actions across public health sectors and departments at multiple scales (discussed further below), as activities one sector (e.g., food safety) can undermine efforts of another (e.g., nutrition or dietetics and food security) and result in less effective actions by frontline practitioners (Speed et al. 2017).

Practitioner oriented capacity building—beyond the health sector

Although the health sector occupies a crucial role in addressing and mitigating the health impacts of climate-driven ocean change, engagement beyond the health sector is needed to address ecological determinants of health such as climate change and pollution (Hancock et al. 2016). Professionals working in climate change preparedness and adaptation, marine spatial planning and integrated coastal zone management, fisheries management, and marine and coastal industries occupy an important role that relates directly, or indirectly, to human health. However, these individuals—and indeed, the sector-based institutions and jurisdictions that define their roles and responsibilities (Le Tissier and Hills 2010)—may not adequately recognize these linkages. For example, climate change adaptation plans for coastal regions in Canada have typically been led by organizations outside of the public health sector (e.g., Ministries of Environment or Ministries of Public Security and Civil Protection) where they have addressed matters such as coastal infrastructure and economies but have lacked a human health focus (Berry et al. 2014). Whether explicitly recognized or not, coastal professionals are increasingly challenged to respond to complex environmental issues that inherently include ecological and social dimensions of health (Biedenweg et al. 2016; Leong et al. 2019). For example, social well-being objectives in fisheries management, in addition to being highly context

Box 1. Enhancing medical practitioner capacity to address and mitigate ocean- and climate-related health issues.

Common clinical presentations of ocean-related health risks, such as those caused by viruses, bacteria or parasites (e.g., *Vibrio* infection) may include nonspecific symptoms like gastroenteritis, diarrhea, and vomiting. Consequently, ocean-related health issues may be misdiagnosed and unreported (Stavric and Buchanan 1997; Khaira and Galanis 2007). To alert and prepare physicians and the supporting public health infrastructure of the potential risk for emerging threats from the marine environment (e.g., *V. vulnificus* infection associated with rising ocean temperatures), health professionals need to become more aware of ocean-related health issues, particularly emerging issues mediated by climate change. Climate change has implications of varying severity for human health in coastal populations and, as such, is of fundamental relevance to future and current physicians (Maxwell and Blashki 2016). While health professions working to address social and ecological determinants of health face considerable challenges (Power et al. 2019), health professionals inherently carry a responsibility and ethical obligation to alleviate suffering and to uphold health in all populations (Solomon and LaRocque 2019; Vogel 2019). As such, they have been instrumental in advocating for environmental health issues like climate change. The Canadian Medical Association, the Canadian Association of Physicians for the Environment, and The Lancet have unanimously recommended that climate change be integrated into all medical and health science curricula (IFMSA 2018). Since July 2017, the accreditation process of the Association of Faculties of Medicine of Canada requires all medical schools to have a social accountability mandate (i.e., "the obligation to direct their education, research and service activities towards addressing the priority health concerns of the community, region, and (or) nation they have a mandate to serve" (WHO 1995)). The social accountability mandate of medical schools extends to planetary health, climate change, and reconciliation issues, as those directly impact the health of the populations they serve. In that spirit, ASPIRE, an international program that recognises excellence in medical education, has now outlined specific criteria on environmental accountability and conservation, including the obligation for medical schools to ensure they actively develop, promote, and protect environmentally sustainable solutions to address the health concerns of the community, region, and the nation they serve (Pearson et al. 2015). Yet, a significant gap remains in the education of medical students and health professionals on this topic, leaving health care professionals with insufficient knowledge and skills to address climate change, particularly with respect to ocean and public health for which complex linkages are still poorly understood. Presently, there is no climate change curriculum within any Canadian medical school programs (Vogel 2019). Medical learners in Canada believe their current teaching is insufficient (Howard et al. 2018) and that they lack the required training on climate change and health issues (Valois et al. 2016). The Canadian Federation of Medical Students has developed a set of climate change, sustainability, and health education topics (including displacement and vulnerable populations, food and water insecurity and quality, changing infectious disease burdens, emergency disaster risk, climate and environmental advocacy, ecological health promotion, remote and rural health, and Indigenous health) and is advocating for their integration into the medical curricula across the country. Similarly, the International Federation of Medical Students Associations, representing over 1.3 million medical students in 135 countries, is also advocating for the inclusion of climate change in medical curricula worldwide (IFMSA 2016). To fill the current gaps in climate change and health medical education, there is an urgent need to integrate climate and ocean change related issues within medical curricula in Canada.

specific, are often poorly defined in fisheries policy, and their inclusion and prioritization is often at the discretion of individual fisheries managers (Pascoe et al. 2014). Research from western Canada has suggested that fisheries management professionals may lack the expertise and experience to integrate social values into fisheries management plans (Sharp and Lach 2003). Similarly, the "lack of sustained capacity and expertise within local authorities" has been highlighted as a key barrier to successful integrated coastal management (Le Tissier and Hills 2010). In the absence of national or provincial accreditation bodies and organizations for coastal professions—which provide a structure to set standards of experience and education, support continuing education opportunities to respond to changes in the professional landscape, and facilitate communication and sharing of best practices across jurisdictions—sector needs for capacity, training, and policy to address social and health dimensions of coastal issues are difficult to ascertain and require further inquiry.

Dedicated structural supports

Restructuring mono-disciplinary fields of inquiry, professions, sectors, and institutions to engage with a range and diversity of ocean and health-related issues presents important logistical, political, financial, and bureaucratic challenges that compound the conceptual and theoretical challenges highlighted above (and which have been discussed more comprehensively by other authors, see for example Cooke et al. 2020). Indeed, overcoming barriers among disciplines and sectors to promote enhanced communication, collaboration, coordination, and coherence is not a trivial undertaking (Rice et al. 2004). Dedicated structural supports and initiatives—including: policies and governance; leadership (institutions, centres, networks, working groups and panels); knowledge exchange opportunities (symposia, workshops, webinars), and funding—may foster conditions that support a more coherent and integrated approach to sustainable marine oceans and human health in Canada.

Policy and governance

Reconciling the health of oceans and people has largely evaded global and national policies and governance structures. Seminal international reports on emerging environmental, and climate-relevant, health issues—including (but not limited to): the Lancet Commission on Planetary Health (Whitmee et al. 2015); Lancet Commission on Pollution and Health (Landrigan et al. 2018); the World Health Oraganization health and climate change report (WHO 2018); the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (Pörtner et al. 2019)—have identified several ocean-related issues (e.g., fisheries destruction, ocean acidification and marine pollution) as priority areas for human health. Despite this, dedicated ocean health initiatives have been largely absent from global fora (Depledge et al. 2019), and ocean governance/policy has traditionally lacked an explicit consideration of human health and well-being. Moreover, global ocean priorities, such as Sustainable Development Goal (SDG) 14—Life Below Water (Meissner 2018), are poorly related across the other sustainable development goals, such as human health (SDG 3), and fail to take into account the global impact of changes in the ocean on human populations worldwide (Singh et al. 2018, 2019). Yet, achieving good health and well-being (SDG 3) depends in several ways on the conservation and sustainable use of oceans and marine resources (SDG 14) (Singh et al. 2018). As proposed by Depledge et al. (2019), the establishment of intergovernmental panels (e.g., IPCC) as well as dedicated initiatives and special task forces (such as efforts to connect biodiversity and human health by the Secretariat of the Convention on Biological Diversity and the World Health Organization (WHOSCBD 2015)) may help connect global priorities related to oceans and human health.

In Canada, administrative, jurisdictional, and regulatory complexities exist between federal, provincial, territorial, municipal, and Indigenous governance responsible for oceans and human health (Ricketts and Harrison 2007; McDorman and Chircop 2012). Oceans policy in Canada has

traditionally suffered from a fragmented approach, resulting in conflict among political, economic, social, and environmental objectives (Berkes et al. 2001). Ocean-related initiatives in Canada, such as Canada's Oceans Agenda by Fisheries and Oceans Canada (DFO) (DFO 2019a), while anchored in references to healthy oceans and resilient coastal communities, have seldom included explicit public health issues within their mandates and policies. To advance an integrated agenda on oceans and human health there is a need to clarify jurisdictional responsibilities, authorities, and legislative mandates. The reader may refer to Sander (2018), Jessen (2011), and Ricketts and Harrison (2007) who provide a comprehensive treatment of the governance and jurisdictional challenges of developing and implementing effective policies and practices for integrated ocean and coastal management in Canada.

Despite the lack of concerted OHH initiatives in Canada, several federally administered research and monitoring programmes exist in Canada that implicitly address ocean-related hazards to human health. For example, the Northern Contaminants Program (NCP), administered by Crown–Indigenous Relations and Northern Affairs Canada, has fostered interdisciplinarity and participatory research on the effects of transboundary chemical pollution on ecosystems and human health in northern Canada for several decades. It provides a notable example of an integrated research and risk communication initiative that seeks to balance both the risks and benefits of the oceans to human health as well as the inclusion of Indigenous knowledge and local priorities into the research agenda. The NCP however is limited to chemical pollution in northern communities. The Canadian Shellfish Sanitation Program—which jointly involves DFO, Health Canada, the Canadian Food Inspection Agency, and Environment and Climate Change Canada—is another notable example of a national integrated ocean-health initiative. However, with limited funding and resources for regular local monitoring and surveillance, the program may favour a precautionary approach to public safety, at the expense of public utility of marine resources by coastal communities. While food safety and food security connect in several ways, these domains have historically been considered separately by public health organizations, policy makers, and researchers (Speed et al. 2017). Furthermore, the CSSP focuses exclusively on acute food safety issues (i.e., HAB and microbiological issues), and other long-term human health concerns from the marine environment, such as those addressed in northern communities by the NCP, are not embedded in any existing national ocean surveillance initiatives. Moreover, there are no national programs that recognize and focus on the benefits of the oceans and the health and well-being of Canadians (including psychosocial dimensions of health), beyond those which recognize economic contributions to marine sectors. Indeed, oceans policy in Canada has adopted a narrower conception of the relationship between humans and oceans than exists in the public narrative (Macdonald 2018).

The jurisdictional landscape of environmental and health policy in Canada is highly complex and therefore requires a more robust analysis of deficiencies and opportunities for environmental and public health policies to address environmental health inequities (Masuda et al. 2008). Where relevant, integrated approaches to support more effective coordination between and among the differing levels of government and sectors (while including other relevant interests) (Ricketts 2018) may be needed to reconcile areas of conflict and ensure actions undertaken in one sector does not inadvertently and negatively impact the other.

Leadership (institutions, centres, networks, working groups, and panels)

Traditionally, government departments and agencies have been segregated by sectoral jurisdictions with specific assignments and responsibilities (Juda 2003). However, as noted by Cárcamo et al. (2013) sectoral agencies are not designed to deal with inter-sectoral issues. Furthermore, ocean and human health includes relevant expertise and professionals in diverse institutions that seldom interact (Fleming et al. 2014). Addressing integrated OHH issues may thus require dedicated leadership to

bring together the appropriate expertise into common interdisciplinary fora such as integrated or interdisciplinary and multi-institutional centres, networks, working groups, and panels (Rice et al. 2004; Sandifer et al. 2013).

In Canada, there are several examples of integrative and multiple disciplinary research networks that address marine and (or) northern issues (e.g., ArcticNet, MEOPAR, Ocean Frontier Institute). Similarly, Canada's Adaptation Platform, a multi-stakeholder forum for collaboration on adaptation action and building resilience across Canada includes a Coastal Management Working Group; however, health is not explicitly counted among its priorities, and there is no distinct human health working group present in the forum. The Public Health Agency of Canada funds six National Collaborating Centres for Public Health (including, the National Collaborating Centre for Environmental Health and the National Collaborating Centre for Indigenous Health) to foster linkages within the public health community to translate and promote the use of existing knowledge and evidence by public health practitioners and policy makers across the country. Beyond this, however, there have not been dedicated institutional and funding initiatives to establish and maintain dedicated OHH research networks, institutions and centres, and programs at the national scale.

The establishment of Centers for Oceans and Human Health in 2004, collaboratively sponsored by the National Institute of Environmental Health Sciences and the National Science Foundation and the establishment of three centers of excellence in oceans and human health led by the National Oceanic and Atmospheric Administration (NOAA) in the United States (**Fig. 1**) (Laws et al. 2008) may serve as an example to promote a more coherent and collaborative effort to tie disparate ocean, health, and climate initiatives in Canada. Similarly, the establishment of dedicated working groups (see for example the Marine Board of the European Science Foundation Working Group on "Oceans and Human Health" (Moore et al. 2013b)) may help develop priority issues, research questions, policies, and capacity development priorities in the areas of oceans and human health in Canada.

Knowledge exchange opportunities

Although natural marine scientists are increasingly called to collaborate with social scientists and policy makers and practitioners, it remains rare for such collaborations to extend to the health sector (Depledge et al. 2013). Knowledge exchange events such as the 1999 conference on "The Interactions Between Healthy Oceans and Human Health " assisted in establishing a framework for research that would ultimately foster the development of the OHH metadiscipline (Tyson et al. 2004) (**Fig. 1**). The conferences and gatherings of major national and international scientific societies (e.g., EcoHealth) could also play an integral role in hosting, convening, or highlighting relevant education and capacity development sessions on OHH (Sandifer and Sutton-Grier 2014). Furthermore, knowledge translation activities and materials such as presentations or seminars, evidence reviews, reports, inventories of resources, fact sheets and summaries, electronic resources, workshops, courses, and webinars may help advance awareness of OHH linkages in Canada.

Funding

Several of the activities and structures highlighted above necessitate dedicated funding. The establishment of the *Oceans Act* in the United States, for example, was met with financial support to implement relevant activities (**Fig. 1**). Although the funding has now come to a close, NOAA continues to explore and expand its connections and contributions in a variety of health-related activities. Research funding in Canada has traditionally been fragmented between three federal granting agencies, with respective foci on health, natural, and social sciences: the Canadian Institutes of Health Research (CIHR), the Natural Sciences and Engineering Research Council (NSERC), and the Social Sciences and Humanities Research Council (SSHRC). Still, some limited funding opportunities exist

across agencies as well as sustained co-operative funding programs such as the Networks of Centres of Excellence (NCE). The NCE program recognized that there are no straightforward solutions to apprehending and finding panacea to complex challenges around important issues for the health (for example COVID-19 pandemic in 2020), environment, economy and well-being of Canadians. Despite its 30-year success, the federal government is ending long-term funding for NCE. The significant transformative research currently supported in NCE will therefore no longer be mobilized into policy. Perhaps the most significant interdisciplinary ocean and human health initiative in Canada, was the Coasts Under Stress project (Dolan et al. 2005; Ommer 2007), jointly supported by SSHRC and NSERC. However, it is notable that the project website highlights the lack of funding as an impediment to further project development (i.e., "Twenty years later, the lack of government net funding has meant no development for this project"; www.coastsunderstress.ca). This mirrors broader shortcomings in research funding and policy development on the influences of the environment on the health of vulnerable populations, such as Indigenous Peoples and coastal populations that bear a disproportionate burden of climate change impacts in Canada (Masuda et al. 2008). As Masuda et al. (2008) recommend, addressing issues of environmental health linkages requires deeper, more fundamental changes to Canada's Tri-Council research agencies' institutional structures.

Conclusion

In this paper we have argued that there is a need to move towards a more holistic climate-sensitive agenda for research, education and training, policy, and practice on oceans and human health in Canada. Attention to the climate–ocean–health nexus is highly relevant in light of the multiple benefits of Canadian oceans and coastal livelihoods that may be threatened by the intensification of resource extraction and development in coastal regions, alluded to in blue economy discourse and "Blue Growth" strategies (Keen et al. 2018). Furthermore, these integrated efforts can support and drive other national and global priorities and movements of sustainable development (Nippon Foundation-Nereus Program 2017), food sovereignty and sustainable food systems (Food Secure Canada 2017), health equity (Marmot et al. 2008), and the human right to food (de Schutter 2012) as well as the rights of, and reconciliation with, Indigenous Peoples (TRC 2015).

The current drive to advance understanding of oceans and human health was set into motion over 20 years ago, catalyzed by the International Year of the Ocean in 1998 (Rice et al. 2004). In the spirit of the forthcoming UN Decade of Ocean Science, we stress the need for multiple Canadian sectors to engage, learn from, and strengthen their capacities regarding the climate-related risks to oceans and their potential consequences for human health and well-being. Ultimately, our joint efforts can contribute to increased societal awareness (from which we must also learn, listen, and collaborate) and motivate the political will to act jointly at various levels to ensure the sustainable continuity of ocean-related health benefits for future generations of Canadians.

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Author contributions

T-AK, HMC, and ML conceived and designed the study. T-AK, PA, PA, MB, HMC, WC, TDE, ML, YO, CP-D, SP, JP, FP, GS, and ML drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

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