Welcome to the Spring/Summer issue of **THE ZONE**, the CZCA digital newsletter.

Announcing Coastal Zone Canada 2018 in St. John's!

The Coastal Zone Canada Associations' biennial conference series is returning to St John's, Newfoundland and Labrador in 2018! CZC'18 will be held on the campus of Memorial University from July 15th to 19th, 2018. The conference venue is located a few minutes from the historical St. John's waterfront, one of the oldest ports in North America.

Keith Mercer, Conference Chair, School of Fisheries, Memorial University

The conference agenda will focus on spatial and temporal scales for coastal management and climate change adaptation. For example, given the conference setting in Newfoundland and Labrador, the transferability of science and lessons learned from large urban centres to smaller rural communities will be explored. Also, the conference will continue addressing the important role of partnerships and collaboration across government, academia, NGO's, and the private sector to manage our coastal and ocean resources.

Details on the call for abstracts and special sessions will be available later this year. Accommodations will take place in a newly constructed residence on campus in close proximity to the conference meetings, plus commercial hotels.

So, mark your calendars and start spreading the word about CZC'18! Plan on bringing the whole family to Newfoundland and Labrador in the summer of 2018!

For more information about the conference and becoming a partner, please contact Keith Mercer at Keith.Mercer@mi.mun.ca

GET IN THE ZONE

Submit your news items for the next issue of The Zone (Fall 2017). We wish to continue the dialogue of coastal zone work across Canada between our biennial conferences, so please consider sharing an update with us to be included in the next issue.

News Items

To submit a news item (maximum 500 words) please send to
thezone@coastalzonecanada.org

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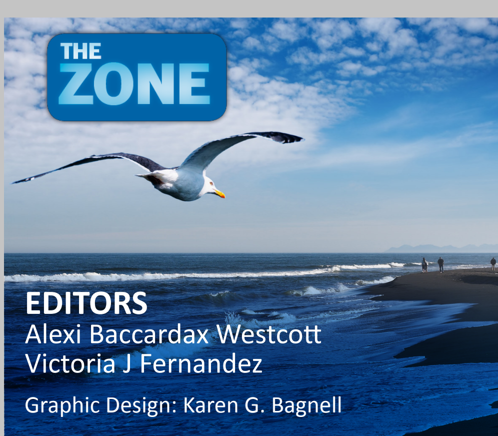
We would like to sincerely thank all of the contributors to this edition of the Zone, the authors of the papers and articles herein, as well as the reviewers.



CALL FOR PAPERS

Please consider submitting a paper to the next issue of the CZCA Newsletter. We are looking for paper submissions of 1000-2000 words on a wide range of topics covering Canada's coastal zone: governance and policy, engineering, ocean science, and social science.

If you wish to submit a paper please submit your abstracts (maximum of 250 words) to thezone@coastalzonecanada.org by September 1st Papers are due October 1st, 2017.

Call for French Editors

The Zone is looking for French speaking or bilingual (French and English) volunteer editors. For further information please contact us at
thezone@coastalzonecanada.org

CZCA Membership

Registration at the biennial conferences automatically includes CZCA membership dues for two years. If you missed the 2016 conference and would like to update your membership or become a new member, please visit our website for more details. The fee is $20/year or $40 for two years.

www.coastalzonecanada.org

Green Shores™: a multi-faceted program for sustainable shoreline development

DG Blair, M.Sc.*

Green Shores, an initiative of the Stewardship Centre for BC (SCBC), promotes sustainable shoreline ecosystems in British Columbia for commercial, residential and park properties. Green Shores has the broad vison of increasing our capacity to address impacts of shoreline development and climate change on shoreline ecology and human well-being. It is a cost-effective and resilient way to address projected one metre sea level rise by 2100 (Lamont et. al., 2014) .

Green Shores' guiding principles are to:

1. Preserve the integrity and connectivity of shoreline processes;
2. Maintain and enhance shoreline habitat diversity and function;
3. Minimize and reduce pollutants to the shoreline environment; and
4. Reduce and reverse cumulative impacts to shoreline systems.

The program was initiated in 2005 by SCBC, with the support of multiple funding partners, to address coastal shore stewardship. It has since expanded to include both marine and lake shoreline environments. The program provides tools for industry professionals in the planning, design and construction fields; local governments; and shoreline property owners interested in minimizing the environmental impacts of their projects in a cost-effective manner (Emmett et al, 2017).
To fulfill its vision, the Green Shores program offers education and training (including a registry for Green Shores trained professionals); support for local governments through a dedicated working group; and shoreline project enrollment and certification for projects both large and small.

Education and Training

Green Shores provides training opportunities for contractors, builders, professionals (biologists, engineers and geoscientists, planners, landscape architects), conservation organizations, and the general public through a series of workshops offered throughout BC, in collaboration with the Restoration of Natural Systems Program at the University of Victoria.

This training was developed based on a community engagement process that identified the needs of property owners, local governments and professionals (Modus, 2015). Those taking the Green Shores Level 2 workshops are added to a registry of trained professionals.

In addition, Green Shores verifier training is offered to professionals interested in assisting project proponents wanting to achieve Green Shores project certification. An evaluation of our training also identified future training needs including an on-line course and an Approved Professional module, with exam, and the development of a cadre of Approved Professionals to assist project proponents with design and construction of Green Shores projects (Blair, 2016).

Local Government Working Group

The SCBC Green Shores program includes a Local Government Working Group, which assists local governments and their NGOs partners with initiation, research and planning tools. This includes development of incentives and awards, public education (workshops and training courses) and assistance with demonstration projects.
In collaboration with partners, SCBC also produces a variety of resources for local government on Green Shores such as educational materials, guides, case studies, and other policy documents; and makes these resources available to the Local Government Working Group members.
The work of the Working Group is especially important considering the need for climate change adaptation plans and the need to effectively implement strategies to integrate Green Shores with other key planning and community engagement processes. The Local Government Working Group generally meets once a month via teleconference and has a 3-year membership commitment.

Shoreline Project Certification

Recognizing the opportunity for rating and certification programs to influence environmentally sensitive design of shoreline projects, SCBC has two Green Shores certification programs.

Green Shores for Coastal Development applies to a broad range of types of coastal shoreline properties, while Green Shores for Homes focuses on residential properties.

Each program has a Credits and Ratings Guide that can be used as a tool for waterfront property owners and managers to develop their properties in a shore friendly way. Information on all of the prerequisites/requirements, credits and maximum points available are provided in the Credits and Ratings Guides. A Green Shores rating is achieved by meeting all prerequisites/ requirements and an additional number of credit points. A shoreline project may achieve different ratings levels, dependent on the points achieved. An example of the process for Green Shores for Coastal Development is provided in Figure 1.

Green Shores for Coastal Development

The Green Shores for Coastal Development guide describes the five Green Shores prerequisites and eleven optional Green Shores credits (Figure 2). The prerequisites address the most critical issues of sustainable shoreline development, including siting of building structures, conservation of critical and sensitive habitats, coastal riparian values and shoreline physical processes (sediment supply, transport and deposition). Green Shores for Coastal Development certified projects must meet all five prerequisite requirements.

Although no points are awarded for these prerequisites, they ensure that the four principles of the Green Shores program outlined above are met; providing a basic "greening goal" for a waterfront development project. Project designs that do not meet all five prerequisites can be quickly screened out of the certification process.

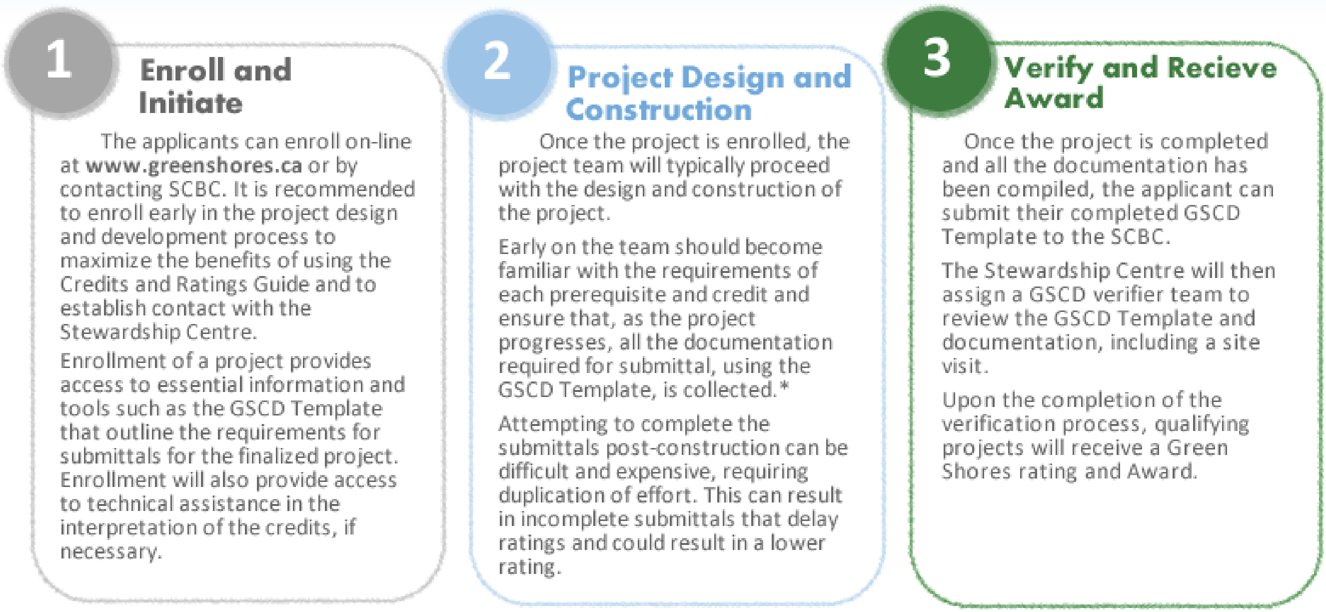


Figure 1: Project certification using the Green Shores for Coastal Development Credits and Ratings guide

By contrast, the eleven optional credits provide a range of opportunities for projects that meet the prerequisites to go beyond basic "green" goals to further reduce the cumulative impacts of waterfront development. The three certification levels—Bronze, Silver, and Gold- are intended to incentivize proponents to higher performance levels than initial design might indicate (Emmett et al, 2017).

Green Shores for Homes

Green Shores for Homes has specific credits within each of four categories. In contrast to the Green Shores for Coastal Development, Green Shores for Homes does not include prerequisite actions. Instead there are four distinct general application requirements that coincide with those typically required for permitting in local jurisdictions, minimizing additional document requirements by the program participants.

A total of 22 specific credits were developed for the four credit categories (Table 1). The Shoreline Process credits address sites with no shoreline protection, building setbacks and actions to reduce or reverse cumulative impacts from existing developments (bulkhead and groin removal). The Soft Shore Protection

Prerequisites	
Prerequisite 1	Siting of Permanent Structures
Prerequisite 2	Conservation of Critical or Sensitive Habitats
Prerequisite 3	Riparian Zone Protection
Prerequisite 4	Conservation of Coastal Sediment Processes
Prerequisite 5	On-Site Environmental Management Plan

Credits		
Credit 1	Site Design with Conservation of Shore Zone	1 to 3 points
Credit 2	Shore Friendly Public Access	1 point
Credit 3	Re-Development of Contaminated Sites	1 point
Credit 4	Climate Change Adaptation Plan	1 to 5 points
Credit 5	Rehabilitation of Coastal Habitats	0.5 to 4 points
Credit 6	Rehabilitation of Coastal Sediment Processes	2 to 3 points
Credit 7	Enhanced Riparian Zone Protection	0.5 to 4 points
Credit 8	Light Pollution Reduction	1 point
Credit 9	Integrated Stormwater Planning and Design	1 to 4 points
Credit 10	Innovation	1 to 2 points
Credit 11	Outreach and Public Education	1 point

Figure 2: Green Shores for Coastal Development: List of Prerequisites and Credits (Green Shores for Coastal Development Credits and Ratings Guide 2016)

Continued on next page

*Figure 3. An example of a Green Shores for Homes project that achieved a Chinook (**Green Shores for Homes**[1]) rating (photo credit: Watershed Company)*

credit encourages alternative approaches to shoreline hardening but requires the applicant to demonstrate that shoreline protection is needed. A number of these credits (Setback, Managed Retreat) include consideration of projected sea level rise.

Although there are a total of 22 available credits, most shoreline projects will only qualify for 5 to 10 as many of the credits, particularly the higher point Shoreline Process credits, are mutually exclusive.[1] This format allows the credit and rating system to apply to a broad range of project types and situations (see example in Figure3). Using the findings of pilot testing, two rating levels were defined based on the number of points achieved by an applicant, Green Shores for Homes 1 "Orca" and Green Shores for Homes 2 "Chinook." (Emmett et al 2017).

[1] For example a property can only qualify for one of the Bulkhead Removal, Soft Shore Protection or No Shoreline Protection Structures credits.

Conclusion

SCBC's Green Shores program offers opportunities to address current issues in shoreline management including:

1. A sound technical framework focused on integrated design approaches with a clear emphasis on cumulative impacts;
2. Guidance and a process for Living Shoreline(Restore America's Estuaries, 2015) approaches that agencies and local jurisdictions can adopt to overcome "institutional inertia", which is caused in great part by lack of a clearly articulated alternative; and
3. A focus on a diverse outreach and education program to meet the needs of property owners, the private sector, local

Credit Category		Credit	Maximum Points Available:		Total Points Available
			Base	Bonus	
Shoreline Processes	1.1	No Shoreline Protection Structures	15	–	15
	1.2	Setback/Impact Avoidance	10	4	14
	1.3	Bulkhead Removal	15	8	23
	1.4	Groin Removal	5	2	7
	1.5	Soft Shore Protection or Enhancement	12	5	17
	1.6	Managed Retreat	10	3	13
Shoreline Habitats	2.1	Riparian Vegetation	10	5	15
	2.2	Trees and Snags	5	1	6
	2.3	Invasive Species	4	–	4
	2.4	Woody Material	3	–	3
	2.5	Overwater Structures	10	–	10
	2.6	Access Design	3	–	3
Water Quality	3.1	Site Disturbance	5	–	5
	3.2	Reduce and Treat Runoff	6	2	8
	3.3	Env. Friendly Building Products	4	–	4
	3.4	Creosote Material Removal	4	0	4
	3.5	Herbicides, Pesticides and Fertilizers	2	–	2
	3.6	Onsite Sewage Treatment	2	1	3
Shore Stewardship	4.1	Shoreline Collaboration	8	–	8
	4.2	Public Information and Education	1	1	2
	4.3	Conservation Easement or Covenant	6	–	6
	4.4	Shoreline Stewardship Participation	2	–	2

*Table 1: Green Shores for Homes Credits and Credit Points (**Green Shore for Homes Credits and Ratings Guide 2015**)*

Continued on next page

governments, planners and regulators as well as shoreline professionals.

Soft shore alternatives are an important and critical way for property owners and managers to address erosion in an ecological manner while also mitigating the impacts of increased shoreline erosion and flooding due to climate change. The Green Shores program provides an important pathway for property owners and managers, with the support of local jurisdictions and professionals, to protect and restore their shorelines, conserving and enhancing shoreline ecology and human well-being for future generations (Emmett et. al., 2017).

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References and Resources

Blair, DG. 2016. Greening Shorelines, Enhancing Resilience in a Changing Climate Development and Delivery of Green ShoresTM Education and Training Formative Evaluation and Training Results. Stewardship Centre for British Columbia. 27 p.

Climate Action Secretariat (CAS) British Columbia Ministry of the Environment. 2013. Sea Level Rise in BC: mobilizing science into action. Victoria, B.C.

Emmett, B., Rueggeberg, H., and K. Litle. 2012. Review of Rating System and Incentive Programs for Residential Development, prepared for Green Shores for Homes Steering Committee.

Emmett, B. DG Blair, and N. Faghin. 2017. Green Shores: using voluntary ratings and certification programs to guide sustainable shoreline development, in Living Shorelines the science and management of nature-based coastal protection. Donna Marie Bilkovic, Ed. CRC Press, Taylor and Francis, Boca Rotan, FLA

Johannessen, J., A. MacLennan, A. Blue, J. Waggoner, S. Williams, W. Gerstel, R. Barnard, R. Carman, and H. Shipman. 2014. Marine Shoreline Design Guidelines. Washington Department of Fish and Wildlife, Olympia, Washington.

Lamont, G., Readshaw, J., Robinson, C., and P. St-Germain. 2014. Greening Shorelines to Enhance Resilience, An Evaluation of Approaches for Adaptation to Sea Level Rise, prepared by SNC-Lavalin Inc. for the Stewardship Centre for B.C. and submitted to Climate Change Impacts and Adaptation Division, Natural Resources Canada (AP040).

Modus. 2015. Green Shores for Homes Pilot Project Summary Report, prepared for Stewardship Centre for B.C.

Restore America's Estuaries. 2015. Living Shorelines: from Barriers to Opportunities. Retrieved from https://www.estuaries.org/images/stories/RAEReports/RAE_LS_Barriers_report_final.pdf

The Risk to British Columbia from a Nearshore Pacific Coast Tsunami

Isabelle Cheff[1,3], Ioan Nistor[1], Dan Palermo[2]

Abstract

This study proposes a conservative approach for an investigation of the potential loss-of-life vulnerability for communities located along the British Columbia coastline to tsunami events using Geographic Information Systems (GIS) software. Potential loss-of-life is assessed using a new quantitative variable, namely available time, which enables a direct comparison between the different vulnerabilities of communities regardless of tsunami hazard. Based on this study, the most vulnerable communities are located on the outer coast of Vancouver Island, where up to 13 populated communities have a high or moderate vulnerability. This study highlights the need for future research on inundation and evacuation modelling of the Canadian Pacific Coast for such extreme events.

Introduction

The threat of tsunami wave often appears distant to Canadians: such recent devastating natural disasters have primarily occurred in the Indian and Pacific Oceans, including the 2004 Indian Ocean Tsunami, the 2010 Chile Tsunami, or the 2011 Tohoku Tsunami in Japan. However, in 1964, the Great Alaskan Earthquake generated a tsunami that resulted in the loss of 131 lives in Alaska. The ensuing tsunami waves travelled south from its Alaskan origin into the Prince William Sound and caused severe damage to several towns on the coast of Vancouver Island, including Zeballos, Hot Spring Cove and Port Alberni. Fortunately, neither this event, nor any other along the Canadian Pacific Coast has caused loss of life since 1964.

Based on historical data, 60% of tsunami events are generated in the Pacific Ocean (NOAA 2016). Approximately 1 tsunami every 2 years strikes the coast of British Columbia, but most do not arrive near populated areas or with large enough waves to disrupt human activities (Leonard et al. 2013; NGDC/WDS 2017). Typically, tsunami can originate from landslides, submarine landslides, and far-field or local earthquakes. The latter mechanism poses the largest threat to the Canadian Pacific Coast due to its proximity to the Cascadia Subduction Zone (CSZ) located within the most seismically active region in the world, the circum-Pacific belt, commonly referred to as the Ring of Fire (Clague et al. 2000, 2003). It is important to note that tsunamis caused by landslides also pose serious risk. In fact, between 1952 and 1975, submarine landslides caused a series of tsunamis in the Kitimat Inlet with waves reaching a maximum height of 8.2 m (Clague et al. 2003). Additionally, unstable sediments in the Fraser River Delta have the potential to generate waves as high as 18 m in the Strait of Georgia, the most populous area along the British Columbia coast (Mosher et al. 2004).

The CSZ extends 1,000 km, stretching from North Vancouver Island to California, with an eastward subduction primarily caused by the Juan de Fuca Plate moving underneath the North American Plate. The seismic history of the CSZ has been reconstructed using paleoeological evidence found in eastuaries and intertidal marshes in Oregon, Washington and Vancouver Island (Clague et al. 2000). From this evidence, it was estimated that the CSZ ruptures at intervals of approximately 500 years, causing earthquake events with magnitudes, Mw , of 8.0 or higher, with the potential to generate major tsunami. The latest event, estimated from paleo-geological evidence, is believed to have occurred in 1700 , as also confirmed by Japenese written historical documents, and from oral histories from North American natives living on Vancouver Island at the time (Satake et al. 2003; McMillan and Hutchinson 2002). This event is believed to have caused tsunami run-ups of 5 m on the outer coast of Vancouver Island as well as run-ups exceeding 15 m in several bays and inlets. Smaller run-ups of between 1 and 5 m were estimated to have occurred in the Straits of Juan de Fuca and Georgia due to wave attenuation in this region (Clague et al. 2000, Leonard et al. 2013).

Growing concerns for tsunami hazard have prompted increased research interest in the United States with the formation of the National Tsunami Hazard Mitigation Program in 1995 (Folger 2015). From this effort, the new stand-alone Chapter 6 "Tsunami Loads and Effects" was developed and adopted in the ASCE (American Society of Civil Engineers) 7-16 standard Minimum Design Loads for Buildings and Other Structures. This new chapter includes tsunami inundation hazard maps for communities on the West Coast of the US and Hawaii, structural design procedures for tsunami resilience, and modeling procedures based on research and case studies. However, no such effort has been initiated in Canada. Modeling of tsunami propagation has focused on the Straits of Juan de Fuca and Georgia, where a significant portion of the population in Western Canada resides: yet it has the lowest tsunami risk from a CSZ event (Clague et al. 2000, Leonard et al. 2013). Tsunami inundation modeling has been initiated at a community level, but it is mostly limited to the Georgia Basin. Currently, there is a need for hazard and risk determination for the small communities along the coast of British Columbia, which prompted the study presented herein.

Study Objectives and Methodology

The primary objective of the study is to determine the vulnerability of communities within the coast of British Columbia to a CSZ-induced tsunami using GIS. The vulnerability is assessed as the loss of life potential, and is evaluated along with the exposure level in terms of the five Tsunami Notification Zones (TNZ) currently used in British Columbia for tsunami warning (Figure 1).

The loss of life potential for coastal communities is evaluated in terms of pedestrian evacuation capabilities using a quantitative variable, namely, the available time ($t_{available}$). It is calculated by subtracting the time required for pedestrians to reach safety (t_{safety}) from the tsunami arrival time ($t_{arrival}$)

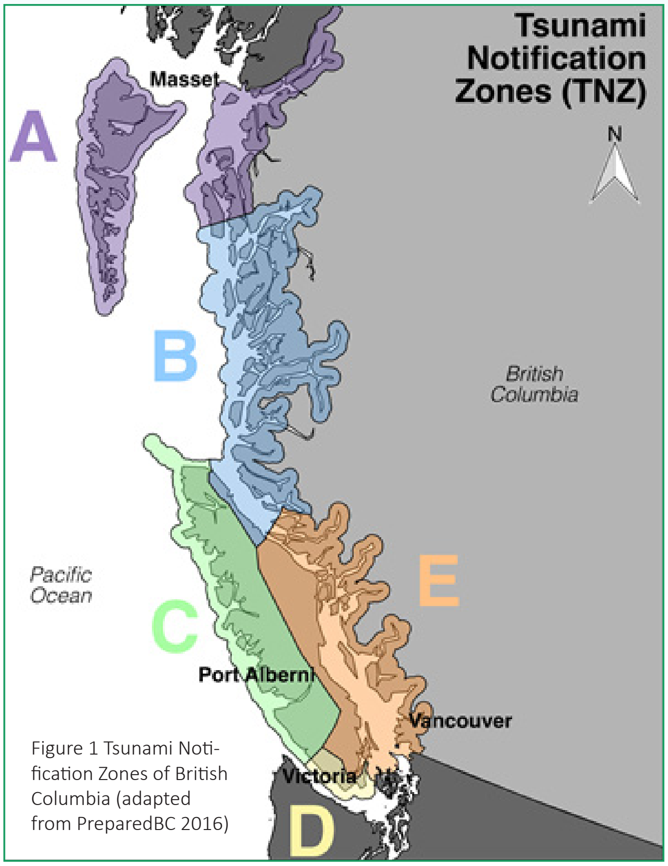

Figure 1 Tsunami Notification Zones of British Columbia (adapted from PreparedBC 2016)

The tsunami wave arrival time was calculated only for the first tsunami wave. Assuming linear wave theory, $t_{arrival}$ is computed using the celerity of a shallow water wave (Eq. 1). The shallow water assumption is used for the tsunami wave propagation due to the significantly long wavelength – compared to that of the wind waves – with respect to the water depth in open ocean. The tsunami wave was modelled using a direct step method from the CSZ source (near the southern tip of Vancouver Island) to the coastline in GIS using bathymetry data. The shallow water assumption does not hold near the shoreline where the celerity of the tsunami wave decreases. However, using this assumption throughout the wave propagation path yields a shorter propagation time and, thus, a conservative estimate.

$$c=(gh)^{0.5} \qquad [1]$$

Given that there are no consistent tsunami inundation maps or pre-determined run-ups for all communities in British Columbia, inundation areas were created at a 2 m interval for a range of run-ups between 3 and 25 m using topographical data with a 0.75 arc seconds resolution (23.2 m in both N-S and E-W direction). The run-up is defined as the maximum topographical elevation at the inland inundation limit. The tsunami inundation zone or the Hazard Zone (HZ) was defined as all area below or equal to the run-up, contrasting to the Safe Zone (SZ) being the area above the run-up. The distance to safety was then computed using the Euclidean distance from every area within the HZ of the communities to the nearest SZ. The time to safety was then calculated by dividing this distance by the pedestrian velocity. Three pedestrian velocities were used: mobility-impairment of 0.89 m/s, the average pedestrian of 1.22 m/s, and a slow run of 1.79 m/s. The built environment, directionality, traffic flux, and speed degradation were not included in the distance and time calculations; therefore, the time to safety is conservative and represents a minimum.

The minimum available times, $t_{available}$, within each community for each TNZ were analyzed forth the computed run-up and compared to the potential range of run-ups determined of the first tsunami wave. The available time provides an independent correlation, which can be used as a method of relating the tsunami vulnerability of communities, regardless of tsunami hazard. The life safety threshold corresponds to $t_{available}$ of 0, as a negative value implies insufficient time for pedestrians to evacuate to safety. The following 3-point scale is adopted to best assess vulnerability:

- High vulnerability: $t_{available} \leq 15$ min
- Moderate vulnerability: 15 min $< t_{available} \leq 30$ min
- Low vulnerability : $t_{available} > 30$ min

Instead of the life safety threshold, a value of 15 min is used as the upper threshold of the high vulnerability category for consideration of the duration of the earthquake, tsunami warning message dissemination and personal effects gathering, such as emergency kits.

Zone	Location	Maximum wave height (m)	Maximum potential run-up (m)[1]	Run-up including factor of safety (50%)	Source
A	Haida Gwaii (west coast)	2.0	4.0 13.9[1]	6.0	(Ng, et al. 1990)b (Leonard and Bednarski 2014)
A	Masset	-	-	10.0	(Village of Masset 2013)
C	Cape Scott	0.8	1.6	2.4	(Whitmore 1993)
C	San Josef Bay	1.4	2.8	4.2	(Whitmore 1993)
C	Tofino	5.8	11.6	17.4	(Cherniawasky, et al. 2007)
C	Ucluelet	6.0	12.0	18.0	(Cherniawasky, et al. 2007)
C	Barkley Sound	7.0	14.0	21.0	(Cherniawasky, et al. 2007)
C	Port Alberni	7.0	16.0[2]	24.0	(Ng, et al. 1990)b
C	South Vancouver Island	8.0	16.0	24.0	Ng, et al. 1990)b
D	Victoria	2.0	4.0	6.0	(Cherniawasky, et al. 2007)
E	Vancouver	1.5	3.0	4.5	(Cherniawasky, et al. 2007)

[1] Maximum run-up calculated as twice the maximum wave height at the shore (Cheff 2016)
[2] Historical maximum run-up from the 2012 Haida Gwaii Tsunami
[3] Maximum run-up computed from numerical model

Table 1 Summary of the maximum wave amplitudes and run-ups along the West Coast of Canada obtained from the literature review of historical evidence and modelled tsunami scenarios.

Zone	Run-up range (m)	Number of communities	Average $t_{arrival}$ (min)	Average $t_{available}$ (min)[1]	Minimum $t_{available}$ (min)[1]
A	3.0 – 11.0	118	157.0	152.5	82.2
B	3.0 – 11.0	147	116.9	113.6	54.9
C	3.0 – 25.0	153	42.1	37.0	-57.7
D	3.0 – 7.0	24	64.5	60.3	39.4
E	3.0 – 5.0	247	137.9	134.2	-7.5

Table 2 Summary properties of each TNZ for most conservative result, the mobility-impaired velocity.
[1] The average and minimum available time presented are only for the corresponding probable run-up range

Figure 2 Minimum available time for communities within Zone E for run-ups between 3 and 25 m, for mobility-impaired (MI), average walking (AW), and slow run (SR) velocity (Cheff 2016)

Figure 3 Minimum available time for communities within Zone C for run-ups between 3 and 25 m, for mobility-impaired (MI), average walking (AW), and slow run (SR) velocity (Cheff 2016)

from the literature, as summarized in Table 1. This range includes an additional 50% as safety factor in addition to 0.5 m for the 50-year sea level rise adaptation, as recommended by the British Columbia Ministry of Environment (2013). The effects of high tides are not included as the run-ups were computed from the higher-high-water coastline. The range of run-ups considered for each zone is presented in Table 2. All communities and First Nation lands, as defined in the British Columbia, were included in this study. However, many First Nation reserves are not permanently inhabited (NRCan 2016; Statistics Canada 2011).

Findings

All communities in Zones A, B and D were determined to have low vulnerability, based on the minimum $t_{available}$ of over 30 min. These high $t_{available}$ values are a result of the large distance the tsunami waves travel from the CSZ source to the northern coast of Zones A and B. For Zone D, this is also due to wave height attenuation, which occurs as the wave passes through the Strait of Juan de Fuca, in addition to the narrow HZ due to the presence of mountainous terrain in the vicinity of the coastal regions.

The statistical distribution of Zone E and C are presented in Figures 2 and 3, respectively, as boxplots. The box represents 50% (or interquartile range, IQR) of the data, between the 25th and 75th percentile and where the black circle represents the median. The lower and upper value of the "whisker's" datum represent 1.5 IQR from the lower and upper quartile, respectively. Values outside of the 25th and 75th percentile are represented by the plus sign (+).

Only one community within its probable run-up range is within the high vulnerability category in Zone E. At a computed run-up of 5.0 m, Richmond has an available time below the life-safety threshold at a mobility-impaired velocity. A 2.0 m increase in the run-up results in the addition of Delta within the high vulnerability category. However, these communities are not of high concern as the minimum $t_{available}$ corresponds to rural areas, where vehicle evacuation can be utilized instead of pedestrian evacuation. This option is likely possible due to the available evacuation time being over one hour ($t_{arrival}$ > 1 hour) and given low traffic conditions in the rural areas. Sea walls are also present around the greater Vancouver area, but these may not be reliable. The walls may have not been designed for protection against tsunami waves and may be damaged during the preceding earthquakes. This region is likely vulnerable to landslide tsunami, which would have a significantly smaller $t_{arrival}$ resulting in a smaller $t_{available}$ value.

The other communities in Zone E have a low vulnerability; removing Richmond and Delta from the dataset results in a minimum $t_{availble}$ of 47.9 min for the zone.

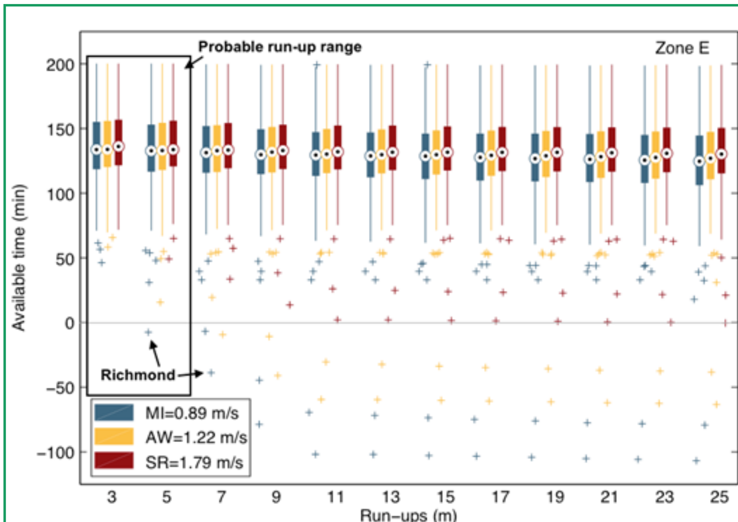

Figure 2 Minimum available time for communities within Zone E for run-ups between 3 and 25 m, for mobility-impaired (MI), average walking (AW), and slow run (SR) velocity (Cheff 2016)

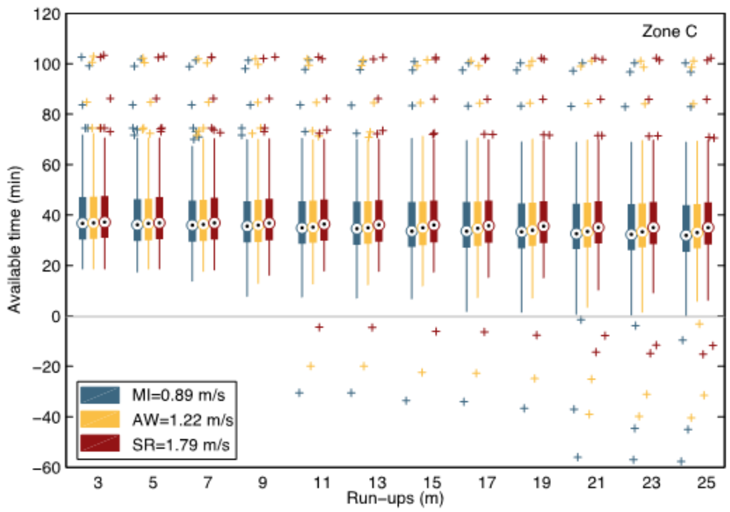

Figure 3 Minimum available time for communities within Zone C for run-ups between 3 and 25 m, for mobility-impaired (MI), average walking (AW), and slow run (SR) velocity (Cheff 2016)

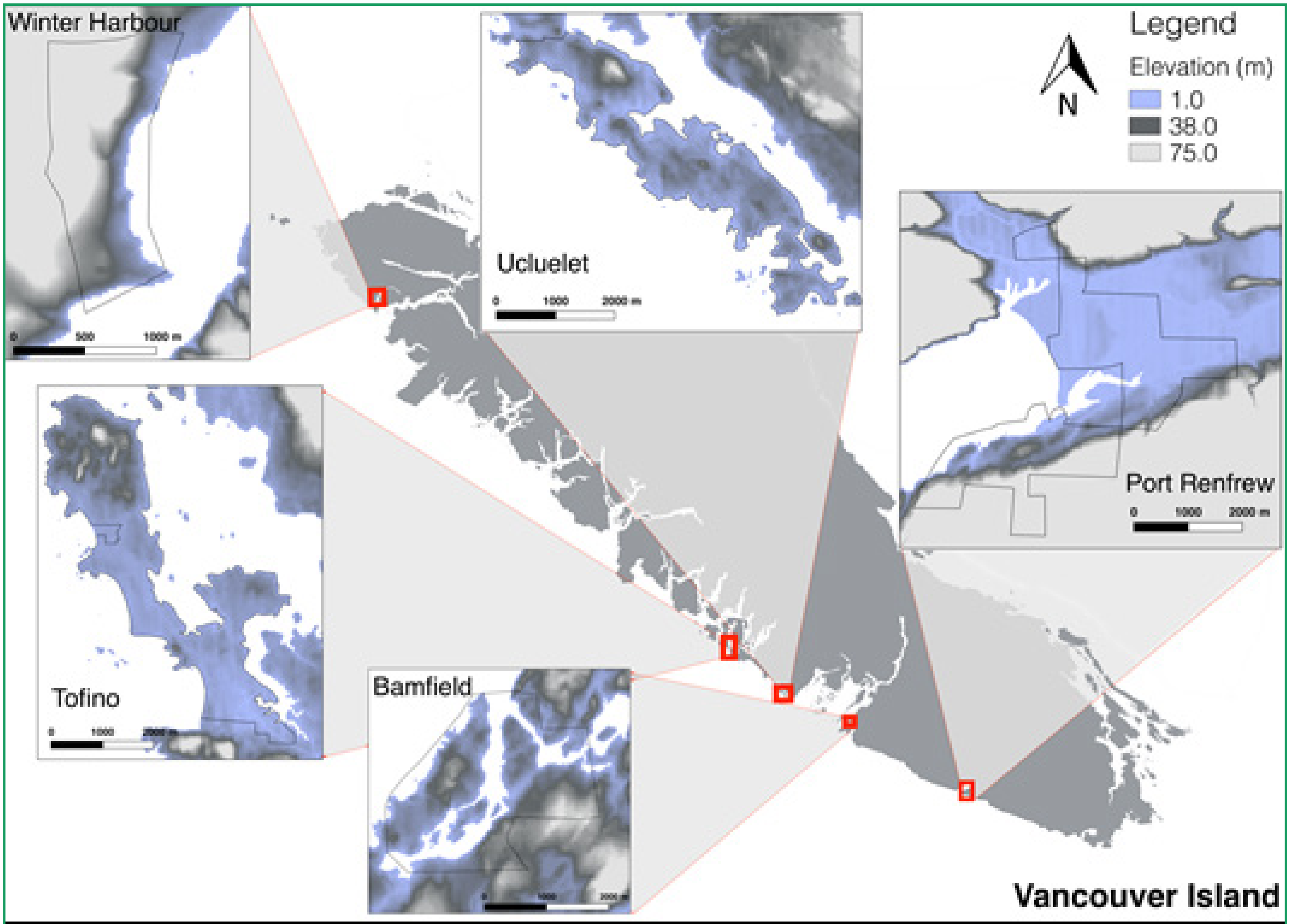

Figure 4 Location of non-indigenous communities with high and moderate vulnerability communities within Vancouver Island, Zone C (Cheff 2016)

Zone C encompasses the western-most coast of Vancouver Island, a highly vulnerable region to CSZ tsunami. This is reflected in the highest expected run-up range of 3.0 to 25.0 m. Zone C has the lowest tarrival and tavailable of 42.1 min and 37.0 min (Figure 3), respectively. The first community to reach high vulnerability and life safety threshold occurs at 7 m and 11 m run-ups, respectively. Additional communities breach the life safety threshold at 21 m run-up. The low tavailable in this zone is mostly attributed to short arrival times from its proximity to the CSZ and to a large increase in distance to safety with increasing run-ups. In total, 65 of the communities within this zone have a moderate or high vulnerability. Out of these 65 communities, 5 are non-indigenous (Figure 4): Bamfield, Port Renfrew, Tofino, Ucluelet, and Winter Harbour; and 8 are First Nation Reserves: Anacla 12, Gordon River 2, Hisnit, Houpsitas 6, Ittatsoo 1, Numukamis 1, Opitasat 1, and Yuquot 1.

Discussion

This study proposes a conservative approach to estimate the potential loss-of-life vulnerability of communities located along the coast of British Columbia to a CSZ tsunami, based on pedestrian evacuation. The most vulnerable communities are located on the western-most coast of Vancouver Island, where close to 13 populated communities have high or moderate vulnerability. Individuals with a slower walking speed than the average adult – people with disabilities, seniors or adults with young children – are at higher risk in Zone C, the outer coast of Vancouver Island. The high vulnerability is reached at 7 m run-up, which is within the probable expected run-ups for this zone. However, healthy adults able to travel at a slow-run pace are still at risk in this zone; this pace would need to be maintained for over 25 min, which can be a difficult task.

In summary, there is a need for further research on tsunami-induced inundation and evacuation modelling of the Canadian Pacific

Coast beyond the Straits of Juan de Fuca and Georgia as the risk of loss of life exists in the less populated regions of the coast. Future research should first concentrate on the communities that were determined to have either high or moderate vulnerability as the conservative approach used in this study may underestimate the available evacuation time.

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References

Cheff, Isabelle. "Tsunami Vulnerability Assessment of the Canadian Pacific Coast Master's Dissertation, University of Ottawa, http://dx.doi.org/10.20381/ruor-501, 2016.

Cherniawasky, Josef Y., Vasily V. Titov, Kelin Wang, and Jing-Wang Li. "Numerical Simulations of Tsunami Waves and Currents for Southern Vancouver Island from a Cascadia Megathrust Earthquake." Pure and Applied Geophysics 164 (2007): 465-492.

Clague, John J., Adam Munro, and Tad Murty. "Tsunami Hazard and Risk in Canada." Natural Hazards (Kluwer Academic Publishers) 28 (2003): 433-461.

Clague, John J., Peter T. Bobrowsky, and Ian Hutchinson. "A review of geological records of large tsunami at Vancouver Island, British Columbia, and implications for hazard." Quaterny Science Reviews (Pergamon) 19 (2000): 849-863.

Folger, Peter. The U.S. Tsunami Program: A Brief Overview. CRS, Congressional Research Service, 2015.

Leonard, L. J., and J. M. Bednarski. "Field Survey Following the 28 October 2012 Haida Gwaii Tsunami." Pure and Applied Geophysics (Birkhäuser) 171 (2014): 3467-3482.

Leonard, Lucinda J., Garry C. Rogers, and Stephane Mazzotti. "Tsunami hazard assessment of Canada." Natural Hazard 70 (2013): 237-274.

McMillan, Alan D., and Ian Hutchinson. "When the Mountain Dwarfs Danced: Aboriginal Traditions of Paleoseismic Events along the Cascadia Subduction Zone of Western North America." Ethnohistory 49, no. 1 (2002): 41-68.

Mosher, D. C., H. A. Christian, J. A. Hunter, and J. L. Luternauer. "Onshore and offshore geohazards of the Fraser River delta." In Fraser River Delta, British Columbia: Issues of an Urban Estuary, Geological Survey of Canada, Bulletin no. 567, by B. J. Groulx, D. C. Mosher, J. L. Leternauer and D. E. Bilderback, 67-79. Natural Resources Canada, 2004.

National Geophysical Data Center / World Data Service (NGDC/WDS): Global Historical Tsunami Database. National Geophysical Data Center, NOAA. doi: 10.7289/V5PN93H7 [03/08/2017]

Natural Resources Canada (NRCan). Aboriginal Lands - British Columbia. 06 01, 2016.

Ng, M.K.-F., P.H. LeBlond, and T.S. Murty. "Simulation of tsunami from great earthquakes on the Cascadia subduction zone." Science 250, no. 4985 (1990): 1248-1251.

NOAA. "NGDC/WDS Global Historical Tsunami Database, doi: 10.7289/V5PN93H7." National Centers for Environmental Information. 2016. https://www.ngdc.noaa.gov/hazard/tsu_db.shtml (accessed 2016).

PreparedBC. Tsunami. 2016. http://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery/preparedbc/know-the-risks/tsunamis (accessed 08 11, 2016).

Satake, K., K. Wang, and B. F. Atwater. "Fault slip and seismic moment of the 1700 Cascadia earthquake inferred from Japanese tsunami description." Journal of Geophysical Research: Solid Earth 108, no. B11 (2003).

Statistics Canada. 2011 Census collection. 12 30, 2015. https://www12.statcan.gc.ca/census-recensement/2011/ref/about-apropos/col-eng.cfm (accessed 09 29, 2016).

The Arlington Group Planning + Architecture Inc.; EBA, a Tetra Tech Company; DE Jardine Consusting; Sustainability Solutions Group;. Sea level rise adaptation primer: A toolkit to build adaptive capacity on Canada's south coasts. Primer, British Columbia Ministry of Environment, 2013

Village of Masset. "Tsunami Evacuation Map." Village of Masset. 2013. http://massetbc.com/images/uploads/content-images/Tsunami-Evacuation-Map-L.pdf (accessed 2017).

Whitmore. "Expected Tsunami Amplitudes and Currents Along the North American Coast for Cascadia Subduction Zone Earthquakes." Natural Hazard 8 (1993): 59-73.

Management of Canadian Arctic Ocean oil and gas developments: Implications for sovereignty, governance and environmental pollution

Tony R. Walker*, Sarah Gulas, Mitchell Downton, Kareina D’Souza, Kelsey Hayden

Abstract

There has been global interest in the exploitation of rich hydrocarbon resources in the Canadian Arctic for decades. However, recent low oil prices, a low carbon economy climate agenda, and technical challenges of Arctic oil extraction have curbed interest in these resources. Despite a recent reluctance to explore and develop an offshore Canadian Arctic drilling industry, a resurgence in oil and gas prices could spark renewed interests that could pose unacceptable risks of pollution from oil spills. These risks are further compounded by complex governance and sovereignty issues between circumpolar nations (Canada, U.S., Russia, Norway, and Denmark). This paper (i) outlines current pollution abatement techniques under Canadian and pan-Arctic national regulations to identify potential gaps; (ii) describes international frameworks for Arctic governance to highlight how problems could arise oil spills migrate to international waters; and (iii) provides recommendations to aid Canadian and international policy-makers regarding pollution abatement methods if offshore oil drilling returns to the Arctic.

Introduction

The Arctic is rich in hydrocarbon resources (USGS 2008). Despite the harsh climate, offshore Arctic drilling began in the 1970s (AMAP 2007). Until recently, global interest in exploitation of these resources were fueled by relatively high global energy prices and declining Arctic sea ice cover (Gulas et al. 2017). However, offshore drilling activity has seen cycles of exploration and development, largely due to wide fluctuations in global energy prices (USEIA 2016). Recent low oil prices, logistical and technical challenges of Arctic oil and gas operations have curbed interest in the Arctic (Gulas et al. 2017). Despite the cyclical nature of Arctic hydrocarbon exploitation, a resurgence in oil and gas prices could spark renewed interest, that could pose unacceptable risks of pollution from oil spills (WWF-Canada 2011).

Five countries with coastal access to the Arctic Ocean (Canada, U.S., Russia, Norway, and Denmark) have long sought opportunities to explore, extract or extend their exclusive rights to these resources (United Nations General Assembly 1982). The United Nation Convention on the Law of the Sea (UNCLOS), established by the United Nations (UN) in 1984, is a treaty that grants certain areas of the Arctic seafloor to five circumpolar nations (e.g., exclusive economic zones [EEZs] of 200 nautical miles [nm]). Norway, Russia, Canada, and Denmark launched projects to provide a basis for seabed claims on extended continental shelves beyond their EEZ (Gulas et al. 2017; Fig 1), but sovereignty issues are still regulated under UNCLOS rules.

Hydrocarbon activity has been focused in relatively shallow water in jurisdictional waters of individual Arctic nations. However, most offshore Arctic hydrocarbon resources remain unexplored, with extensive Arctic continental shelves (7 million km2) and international waters beyond continental shelves (6 million km2) (USGS 2008; Fig 2). Recent estimates of total global undiscovered Arctic Ocean oil and gas reserves are 13 and 30%, respectively, with much of this extending beyond Arctic nations’ jurisdictional waters (USGS 2008). Complex sovereignty issues are further compounded because future Arctic hydrocarbon resource development poses extreme logistical and

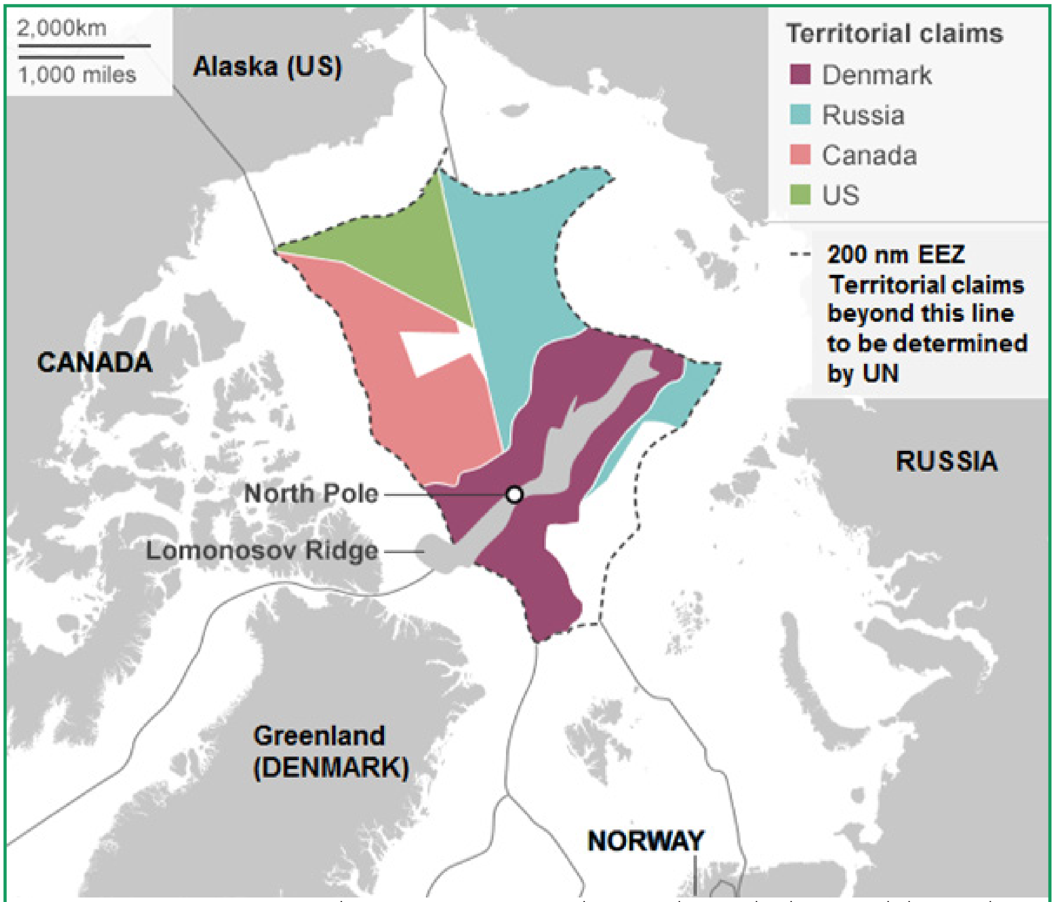

Fig 1. Five Arctic Ocean nations showing 200 nm EEZ jurisdiction and unresolved territorial claims to be determined by the UN (adapted from USGS 2008).

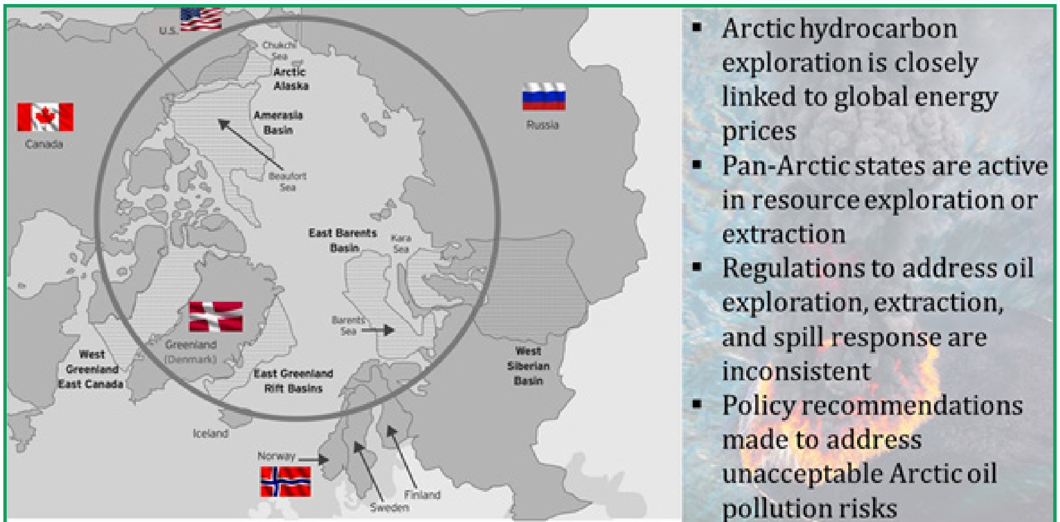

Fig 2. Arctic Ocean potential offshore petroleum resource development areas (adapted from USGS 2008 and Gulas et al. 2017).

environmental challenges (AMAP 2007). Risks from blow-outs and pollution from offshore drilling, production, and transportation are widely recognized because of extreme seasonality, fragile ecosystems, persistence of hydrocarbons at low temperatures, and slow ecosystem recovery (WWF-Canada 2011).

Canadian offshore drilling began in the Beaufort Sea and Mackenzie Delta in the early 1970s (primarily in coastal regions) and has been subject to cycles of energy exploration and development for decades. In the mid 1980s, world oil prices and oil demand began to decline rapidly, preventing further hydrocarbon exploration in the Canadian Arctic at that time. However, large offshore areas in deeper water of the Beaufort remain unexplored with potential for major oil and gas discoveries. In 2007, due to increasing global oil prices and federal government efforts to build Canada's energy economy, exploration licenses were let in deep offshore waters. Despite huge investments in oil and gas exploration in the Canadian Arctic, there has been no significant commercial production (Gulas et al. 2017).

Internationally, several agreements have been signed regarding emergency response regulations and procedures for Arctic oil and gas activities (AMAP 2007). However, the ability of Arctic nations to respond to oil spills which could cross nautical boundaries is limited. The Arctic Council, an intergovernmental forum composed of eight Arctic states, was created to address these challenges (Arctic Council 2016). Arctic states that have recently conducted offshore oil and gas activity have established systems for emergency preparedness that follow Arctic Council guidelines developed specifically for the Arctic. However, increasing accessibility of the Arctic raises concerns about international emergency preparedness and oil spill pollution prevention. These concerns were highlighted by the Deepwater Horizon disaster in the Gulf of Mexico in 2010, which raised serious concerns over responsibility and effectiveness of emergency oil spill preparedness in the extreme Arctic environment (WWF-Canada 2011).

There are many techniques to help mitigate potential Arctic drilling pollution. One is a predictive management tool known as strategic environmental assessment (SEA), which have advantages over project-focused environmental impact assessments (EIAs) (AMAP 2007). Noble et al. (2013) criticized EIAs for their narrow project-focus and their reactionary approach to cumulative effects. SEAs account for regional environmental issues at the outset of decision-making processes before irreversible development are made. For Arctic offshore oil drilling, SEAs can be instituted prior to project approval to predict if certain bodies of water may be harder to drill than others, and management decisions can be altered accordingly. The second pollution abatement technique is same-season relief wells (SSRW). Same-well intervention techniques allow for safe entrance into wells for purposes other than drilling, effectively minimizing risks of unsecured blowouts for extended periods (WWF-Canada 2011). The ability to respond to blowouts within a seasonal drilling window is particularly important in the Arctic where the window to respond to emergencies is very short. If offshore oil leaks (or explosions) do occur, SSRWs can be commissioned quickly to help control the situation. Lastly, emergency preparedness techniques can aid abatement if spills occur (Knol and Arbro 2014).

Current governance structure for pollution abatement

Offshore oil and gas exploration in the Beaufort Sea includes an extensive and complex regulatory framework, overseen by federal and territorial government plus other regulatory agencies (Gulas et al. 2017). Potential oil and gas development projects undergo specific EIA and permitting overseen by the National Energy Board (NEB 2014). However, planning and assessing impacts of offshore exploration and development in the Beaufort Sea requires project-based EIA, although current federal legislation exempts exploratory work from detailed level EIAs (Noble et al. 2013). A major spill in the Canadian Arctic would be challenging to address, because of the region's inability to support a large influx of response personnel. Furthermore, the shallow Beaufort Sea would also complicate the staging of Canadian Coast Guard ship based operations, although an extensive open water season in Canada's Arctic could increase the period for navigation by vessels (Walker et al. 2008).

Some pan-Arctic states have stronger management regulations for pollution abatement than others. Denmark and Norway have comprehensive emergency response regulations in place compared to the other three states. They have developed national systems for responding to oil pollution by prioritizing areas of special ecological significance most likely to be impacted by a potential spill (Knol and Arbro 2014). Norway's national regulations require the most extensive abatement techniques regarding oil spill preparedness, as they are the only country that requires SEAs to be completed before Arctic projects are approved. The Government of Canada recognizes Norway as progressive in pollution abatement and a leader in terms of environmental preparation. Most pan-

Arctic states acknowledge that if an oil spill occurs within national EEZs, transboundary risks should be anticipated and prepared for (Arctic Council 2009). Arguably, there remains significant and unacceptable environmental risks, regardless of individual Arctic nation preparedness or strong regulatory frameworks (WWF-Canada 2011).

International implications for future oil spill preparedness

Policy-makers should update their existing frameworks to resemble Norway's. This may be relevant should Arctic oil drilling becomes attractive again. Bilateral agreements between countries should be bolstered to help coordinate cleanup efforts in case of potential spills. All three abatement techniques help mitigate potential conflicts between nations should an oil spill occur between national waters. SEAs may be utilized within these agreements before projects are initiated to help reduce potential risks for all pan-Arctic states. SSRWs can be mandatorily instituted to ensure mitigation of a spill (should an incident occur), and a coordination of emergency task forces between affected countries should be in place to effectively control the situation.

These pollution abatement techniques are especially relevant for Arctic drilling because oil spills could leak uncontrollably for months if they were to occur prior to winter. For example, if a spill were to occur within Russian jurisdiction, the oil could easily migrate to Alaskan waters. Regional agreements are currently in place for these specific circumstances, but they could be updated to stay in line with current technology and abatement techniques (Arctic Council 2009). The five Arctic states are also part of the Arctic Council, which has international and regional regulations in place to tackle potential pollution moving past sovereign boundaries. Current oil spill response is primarily focused on ice-free Arctic regions. Modern equipment and techniques are not designed for combating spills in ice-covered waters (AMAP 2007). Limited capacity of response equipment and techniques to clean oil spills has been highlighted by Knol and Arbo (2014), who suggest that ≤10–20% can be cleaned mechanically. During the Deepwater Horizon oil spill in the Mexican Gulf in 2010 (where 48,000 people, 6500 vessels, and 125 aircraft were involved during peak cleanup), <3% of spilled oil was recovered using mechanical equipment (Knol and Arbo 2014), Challenges of Arctic ice cover, a harsher climate, and remoteness could prove much more demanding for response teams compared to lower latitudes. Ultimately, the current stagnant climate of Arctic drilling could prove beneficial for environmental advocates, as it gives a chance for technology and abatement techniques to be incorporated into national and international policies. This may change policies surrounding energy use and extraction, but also direct policy efforts toward pollution abatement techniques.

Future recommendations for pollution abatement techniques

An appropriate risk framework should distinguish between acceptable, tolerable and unacceptable risks associated with the petroleum industry, including impacts of industrial activity on particularly sensitive areas and potential risks posed by hydrocarbon releases. WWF-Canada (2011) argue that a "polluter pays" principle should fully apply, to enhance incentives for industry to avoid spills and to ensure funds are available for full response, cleanup, restoration and compensation. However, risks associated with oil drilling in the Arctic are so numerous and significant that WWF-Canada (2011) claim they are unacceptable and recommend a "precautionary approach" based on limited current preparedness and technology.

There remains limited technological capacity to prevent and react to Arctic oil spills. Same-well and SSRW intervention techniques may be required in the future, and are currently required by four Arctic nations, including Canada, Norway, U.S, and Denmark (Gulas et al. 2017). However, they currently have limited (5-10%) success and may create unintended consequences. The ability to respond to a blowout emergency within a short Arctic seasonal drilling window is particularly important. The industry has already acknowledged difficulties of drilling SSRWs in the Arctic, meaning that cleanup in Arctic waters could take multiple seasons. Remoteness of the region also brings logistical challenges which could cause further delays for cleanup operations. Even if successful, relief wells may take too long for a same-well intervention technique to maintain control.

A significant oil spill in Arctic waters could have extensive and long-term impacts. Abilities to respond to oil spills in the Arctic is extremely limited, posing significant challenges for implementing pollution prevention techniques (Knol and Arbo 2014). Furthermore, there are few effective technologies to contain and clean up oil spills in Arctic sea ice, regardless of season (AMAP 2007). Development of technologies, regulations and adequate response techniques may help mitigate potential negative impacts, particularly for oil under ice and broken ice. Knol and Arbo (2014) argue that mobile preparedness teams should be established to compensate for lack of human and technical resources in remote Arctic areas during emergencies. Standards should be supported by in situ equipment and infrastructure, as well as resource sharing arrangements that allow timely and appropriate preparedness and response should an incident occur.

Concerns remain that national regulations vary in approach for pollution abatement techniques in ice-covered regions. Given the potential for oil pollution to impact several national jurisdictions, existing governance framework for offshore oil and gas activities in the Arctic require strengthening, especially oil spill prevention, containment, and response. Planning tools to predict oil and gas impacts (such as SEA) remain underdeveloped in comparison to project-based EIA in offshore Arctic developments. Regional or pan-Arctic SEAs, rather than project-based EIAs, should be utilized to improve pollution prevention, oil spill response, and cumulative effects. With varying levels of success, it would be difficult for countries to rely on these techniques as safeguards from oil spills. Future Arctic Ocean policy related to oil and gas developments may need to rely on stronger international agreements and cooperation via the Arctic Council.

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References

Arctic Council Arctic Oil and Gas. AMAP Working Group (Arctic Monitoring and Assessment Programme): Oslo, 2007. p. 57.

Arctic Council. Protection of the arctic marine environmental working group: Arctic offshore oil and gas guidelines. Nordurslod, Iceland: Arctic Council, 2009.

Arctic Council. The Arctic Council: A Background. 2016. Retrieved from: (http://www.arctic-council.org/index.php/en/about-us) (accessed 08.03.16)

Gulas, S., Downton, M., D'Souza, K., Hayden, K., Walker, T. R. Declining Arctic Ocean oil and gas developments: Opportunities to improve governance and environmental pollution control. Marine Policy, 2017. 75, 53-61.

Knol, M., Arbo, P. Oil spill response in the Arctic: Norwegian experiences and future perspectives. Marine Policy, 2014. 50, 171-177.

NEB (National Energy Board). Environmental Assessment Report for the Northeastern Canada 2D Seismic Report (Baffin Bay/Davis Strait). Government of Canada, 2014. Retrieved from: (https://www.neb-one.gc.ca/nrth/dscvr/2011tgs/nvssssmnt/nvssssmnt-eng.html#s6) (accessed: 14.01.16).

Noble, B., Ketilson, S., Aitken, A., Poelzer, G. Strategic environmental assessment opportunities and risks for Arctic offshore energy planning and development. Marine Policy, 2013. 39, 296-302.

U.S Energy Information Administration (USEIA) 2016a. Cushing, OK WTI Spot Price FOB (Dollars per Barrel). January 1986 to January 2016. Retrieved from (http://tonto.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=M) (accessed: 05.04.16)

United Nations General Assembly. Convention of the Law of the Sea. 1982. Retrieved from: (http://www.refworld.org/docid/3dd8fd1b4.html) (accessed 17.03.16)

USGS. Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle. USGS Fact Sheet 2008-3049.

Walker, T.R., Grant, J., Jarvis, P. Approaching freshet beneath landfast ice in Kugmallit Bay on the Canadian Arctic Shelf: evidence from sensor and ground truth data. Arctic, 2008. 61, 76-86.

WWF-Canada Arctic Offshore Drilling Review, NEB File: OF-EP-Gen-AODR 01 Additional Response to CFI #1 and #2. p 72, 2011. Retrieved from: (http://awsassets.wwf.ca/downloads/wwf_canada___submission_to_neb_review_april_2011.pdf) (accessed: 02.02.16).