A Section 508–conformant HTML version of this article
is available at https://doi.org/10.1289/EHP3397.

Associations between Living Near Water and Risk of Mortality among Urban Canadians

Dan L. Crouse,[1,2] Adele Balram,[2] Perry Hystad,[3] Lauren Pinault,[4] Matilda van den Bosch,[5,6] Hong Chen,[7,8,9] Daniel Rainham,[10] Errol M. Thomson,[11] Christopher H. Close,[12] Aaron van Donkelaar,[13] Randall V. Martin,[13,14] Richard Ménard,[15] Alain Robichaud,[15] and Paul J. Villeneuve[16]

[1]Department of Sociology, University of New Brunswick, Fredericton, New Brunswick, Canada
[2]New Brunswick Institute for Research, Data, and Training, Fredericton, New Brunswick, Canada
[3]College of Public Health & Human Sciences, Oregon State University, Corvallis, Oregon, USA
[4]Health Analysis Division, Statistics Canada, Ottawa, Ontario, Canada
[5]Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, British Columbia, Canada
[6]School of Population and Public Health, University of British Columbia, Vancouver, British Columbia, Canada
[7]Public Health Ontario, Toronto, Ontario, Canada
[8]Institute for Clinical Evaluative Sciences, Toronto, Ontario, Canada
[9]Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada
[10]Healthy Populations Institute, Dalhousie University, Halifax, Nova Scotia, Canada
[11]Environmental Health Science and Research Bureau, Health Canada, Ottawa, Ontario, Canada
[12]Esri Canada, Victoria, British Columbia, Canada
[13]Department of Physics & Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, Canada
[14]Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, USA
[15]Air Quality Research Division, Environment and Climate Change Canada, Dorval, Quebec, Canada
[16]Department of Health Sciences, Carleton University, Ottawa, Ontario, Canada

Background: Increasing evidence suggests that residential exposures to natural environments, such as green spaces, are associated with many health benefits. Only a single study has examined the potential link between living near water and mortality.

Objective: We sought to examine whether residential proximity to large, natural water features (e.g., lakes, rivers, coasts, "blue space") was associated with cause-specific mortality.

Methods: Our study is based on a population-based cohort of nonimmigrant adults living in the 30 largest Canadian cities [i.e., the 2001 Canadian Census Health and Environment Cohort) (CanCHEC)]. Subjects were drawn from the mandatory 2001 Statistics Canada long-form census, who were linked to the Canadian mortality database and to annual income-tax filings, through 2011. We estimated associations between living within 250 m of blue space and deaths from several common causes of death. We adjusted models for many personal and contextual covariates, as well as for exposures to residential greenness and ambient air pollution.

Results: Our cohort included approximately 1.3 million subjects at baseline, 106,180 of whom died from nonaccidental causes during follow-up. We found significant, reduced risks of mortality in the range of 12–17% associated with living within 250 m of water in comparison with living farther away, among all causes of death examined, except with external/accidental causes. Protective effects were found to be higher among women and all older adults than among other subjects, and protective effects were found to be highest against deaths from stroke and respiratory-related causes.

Conclusions: Our findings suggest that living near blue spaces in urban areas has important benefits to health, but further work is needed to better understand the drivers of this association. https://doi.org/10.1289/EHP3397

Introduction

A growing body of literature has demonstrated positive associations between exposures to natural environments (mostly green spaces) and health (Hartig et al. 2014; van den Bosch and Ode Sang 2017), but few studies have looked at associations with exposures to blue spaces (e.g., rivers, lakes, coasts; Gascon et al. 2017). Studies on greenness (i.e., green vegetation) and greenspace (e.g., parks or other natural areas) have suggested benefits to health through various pathways, including stress reduction (Bowler et al. 2010b; Gascon et al. 2018), improved immunoregulation (Rook 2013), increased physical activity (Sallis et al. 2016), and increased social interactions (de Vries et al. 2013). Natural environments also benefit health by regulating ecosystem services, such as by reducing urban heat exposure (Bowler et al. 2010a) and improving air (Nowak et al. 2014) and water quality (Livesley et al. 2016). These pathways contribute to explaining reduced risks of mortality from cardiovascular and nonaccidental causes that have been associated with greenness exposure (Crouse et al. 2017; James et al. 2016; Villeneuve et al. 2012).

Research suggests that there is, in general, a higher preference for views of blue spaces, both freshwater and marine, in comparison with views of most other environments (White et al. 2010). This finding helps explain observed restorative experiences (including feelings of happiness (Völker and Kistemann 2013), stress recovery (Nutsford et al. 2016), improved self-reported health (Völker et al. 2018; Völker and Kistemann 2011), and life satisfaction (Brereton et al. 2008)) associated with views of blue space. Recent studies also suggest a positive impact on birth weight (Glazer et al. 2018). Some studies also suggest that the sounds of water may have an effect on stress recovery (Annerstedt et al. 2013). Systematic reviews (Bowler et al. 2010b; Gascon et al. 2017) have shown that the evidence for an effect of blue space exposure on most health outcomes, such as self-reported general health, mental health, physical activity, obesity, and cardiovascular-related conditions, is either inconsistent or limited. These inconsistencies may be due to contextually

Address correspondence to D.L. Crouse, PhD, Dept. of Sociology, University of New Brunswick, 9 Macaulay Lane, Tilley Hall, Room 20, Fredericton, New Brunswick, Canada, E3B 5A3. Telephone: (506) 458-7436. Email: dlcrouse@gmail.com

Supplemental Material is available online (https://doi.org/10.1289/EHP3397).

The authors declare they have no actual or potential competing financial interests.

Received 23 January 2018; Revised 21 April 2018; Accepted 3 June 2018; Published 24 July 2018.

determined relationships but also to a large heterogeneity in terms of, for example, study designs and exposure metrics.

To our knowledge, only one earlier study has investigated the association between blue spaces and mortality; Burkart et al. (2016) reported that living within 4 km of water modified heat-related mortality among elderly subjects in Lisbon. Canada is an ideal place for studying the effects on health from blue spaces, given that it is bordered on three sides by oceans and has more than 3 million lakes, including the Great Lakes and more than 560 others that are larger than 100 km^2 in area (Schindler 2009). Many of Canada's largest cities are located on large lakes (e.g., Toronto, Hamilton), along major rivers (e.g., Ottawa, Montreal), or along ocean coastlines (e.g., Vancouver, Halifax), and therefore, a substantial portion of Canada's urban population has nearby access to, and residential views of, open water and blue space. Here, we examine whether living near blue spacea is associated with decreased risk of dying from cause-specific mortality among urban, nonimmigrant Canadian adults, while controlling for a wide-range of individual and contextual covariates, along with exposures to ambient fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3), and residential greenness.

Methods

The Study Cohort

The 2001 Canadian Census Health and Environment Cohort (CanCHEC) has been described in detail elsewhere (Pinault et al. 2016). Briefly, the full cohort is a nationally representative sample of approximately 3.5 million Canadian adults who responded to the mandatory 2001 Statistics Canada long-form census (1 in 5 households) and who have been linked to the Canadian mortality database and to annual income-tax filings through 2011 (Pinault et al. 2016). The CanCHEC dataset was created under the authority of the Statistics Act and approved by the Executive Management Board (reference no. 045-2015) at Statistics Canada. This approval is equivalent to that of standard research ethics boards. Counts presented here have been rounded randomly to the nearest five for institutional confidentiality. Individuals were eligible for the cohort if they were ≥ 19 years of age; were a usual resident of Canada on the census day; were not a long-term resident of an institution; and had filed a tax return during the follow-up period ($\sim 95\%$ of the adult population ($18+$) files a tax return in any given year). The linkage to the annual income tax files provided annual six-digit mailing address postal codes, which allowed us to consider subjects' annual residential mobility. In urban areas, postal codes correspond to one side of a city block or to a single apartment building. Missing postal codes were imputed using a method that has been applied and validated elsewhere (Pinault et al. 2017).

Here, we excluded immigrants, given that they tend to have much better health status and health behaviors than do the Canadian-born population, with patterns persisting for upwards of 20 y following immigration (Ng 2011). The present study is limited to respondents living in the 30 largest census metropolitan

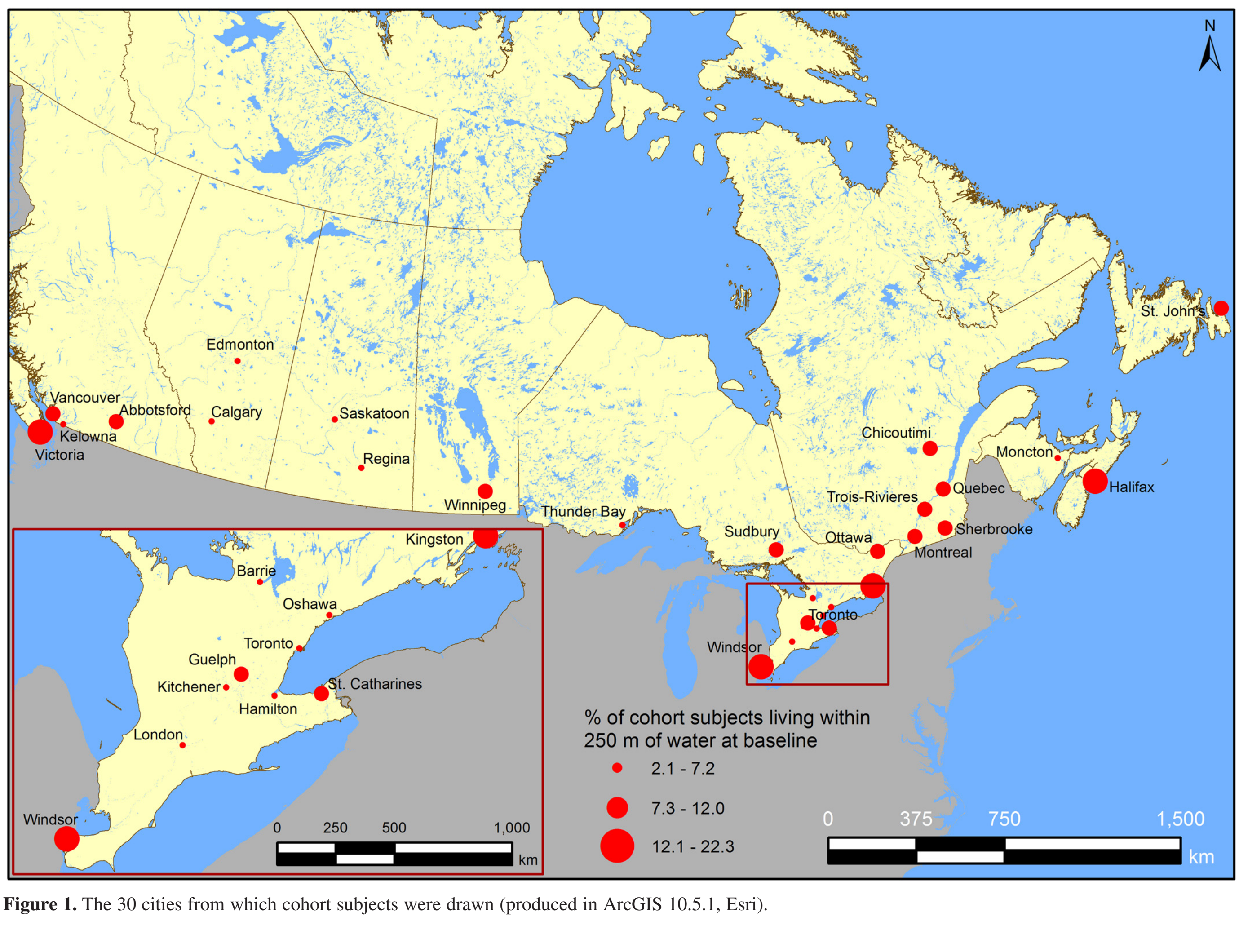

Figure 1. The 30 cities from which cohort subjects were drawn (produced in ArcGIS 10.5.1, Esri).

areas (CMAs; i.e., cities with populations greater than 100,000; Figure 1) according to population data from 2006 (the midpoint of our follow-up period). We also restricted our study to subjects age 25–89 at baseline due to lower rates of successful record linkages to tax files among younger and older subjects.

Assignment of Residential Exposure to Blue Spaces

We sought to identify subjects who live in close proximity to blue spaces and whose daily activities therefore are likely to bring them in contact with, or views of, blue spaces. We therefore identified potential exposures to blue spaces within 250 m of subjects' residence with geospatial data developed by Statistics Canada describing natural hydrographical features, including lakes, large reservoirs, rivers, and coastal waters, across Canada (Statistics Canada 2011). This dataset does not include ponds or constructed features, such as pools. We used ArcGIS 10.5 (Esri) to create a binary variable that indicated the presence (or not) of any water feature within this distance of subjects' residence during each year of follow-up. That is, exposure was reassigned annually to account for residential mobility. It is possible that a buffer of 250 m will include blue spaces that may not be accessible or visible from the subject's residence; however, it captures broadly the area immediately around the home, where exposure to or contact with water is likely on a regular basis. Although there is no consensus in the literature on the most relevant size of buffer around someone's home to assess benefits to health associated with nature exposures, we chose 250 m, given that others have reported associations between mortality and residential greenness within this distance (Crouse et al. 2017; James et al. 2016). As described below, however, we consider associations based on larger buffers also.

Main Statistical Analyses

We used Cox proportional hazards models to estimate associations between living near blue space and several mortality outcomes. Hazard ratios (HRs) were stratified by sex, by five-year age groups, and by CMA (to ensure that subjects were compared statistically only with others of the same age, sex, and residence within the same city). Subjects were censored at date of death or if they had moved away from the study cities.

We adjusted our models for the following individual-level risk factors for mortality: aboriginal identity, visible minority status, marital status, highest level of education, employment status, and household-income adequacy deciles. Visible minorities are persons (other than Aboriginal persons) who self-identify as non-Caucasian in race or nonwhite in color. Income adequacy deciles are calculated from the ratio between the pre-tax income of economic families to the Statistics Canada low-income cut-off for family and community size, adjusted for regional economic differences (Pinault et al. 2016). We also controlled for neighborhood-level socioeconomic characteristics, which may contribute to mortality risk independently of personal socioeconomic profiles. Time-varying contextual variables were calculated using data from the closest census year (i.e., 2001, 2006, or 2011) and were adjusted for regional variations across Canada (i.e., census-division means subtracted from census-tract means) describing the proportion of unemployed adults age 25+, the proportion of adults age 25+ who had not completed high school, and the proportion of individuals in low-income families. Census tracts correspond roughly to the size of a neighborhood, and census divisions correspond roughly to the size of a city. To indicate living in a denser, urban core, as opposed to living in more suburban areas of a city, we also adjusted our models with a time-varying log of neighborhood population density (persons per km^2) at the scale of dissemination areas from the closest census year. Dissemination area geography corresponds to one or more city blocks, comprising 400 to 700 people.

Additionally, we adjusted our models for estimates of exposure to ambient air pollution from existing models and observations of $PM_{2.5}$, O_3, and NO_2 concentrations. We include these here because reduced exposure to air pollution could mediate the pathway between exposure to blue spaces and health. Each of these datasets has been described previously (i.e., $PM_{2.5}$: van Donkelaar et al. 2015; O_3: Robichaud and Ménard 2014; NO_2: Hystad et al. 2011), and used in published epidemiological analyses (Crouse et al. 2015, 2017). Briefly, the $PM_{2.5}$ data are satellite-derived annual estimates at a spatial resolution of about 1×1 km. For O_3, we used the 8-h average daily maximum concentrations obtained from model-observation data fusion at a resolution of $\sim 21 \times 21$ km in the warm seasons from 2002 to 2009. The NO_2 data were derived from a national 2006 land-use regression model developed from observations from fixed-site stations and incorporating satellite-derived NO_2 estimates and land-use predictors. Ozone and NO_2 estimates were year-adjusted using ground-based time series measurements.

Last, we adjusted our models for residential greenness (i.e., remotely sensed Normalized Difference Vegetation (NDVI)) estimated within 250 m of subjects' residence, which has been associated with protective effects for mortality in this (Crouse et al. 2017) and other cohorts (James et al. 2016; Villeneuve et al. 2012).

We developed hazard models for seven common causes of mortality, including all nonaccidental causes (ICD-10: A to R); cardiovascular plus diabetes (ICD-10: I10 to I69, E10 to E14); cardiovascular diseases (ICD-10: I10 to I69); ischemic heart disease (ICD-10: I20 to I25); cerebrovascular disease (ICD-10: I60 to I69); nonmalignant diseases of the respiratory system (ICD-10: J00-J99); dementia or Alzheimer's disease (ICD-10: F01–F03, G30); and, as a negative control (i.e., as a theoretically unrelated outcome): external/accidental causes (ICD-10: V to Y).

Additional Analyses

We also tested for effect modification by age, sex, income adequacy decile, and education in models with nonaccidental mortality. For this testing, we used Cochran's Q-statistic (Axelson 1980) to test heterogeneity in the HRs. Statistical analyses were performed in SAS 9.4 (SAS Institute, Inc.) and R (version 3.3.3; R Core Team).

Some people, perhaps those who are generally healthier than others, may choose and be able to afford to live near to water. For this reason, we performed a matched cohort analysis, which allows for reducing selection bias and approximating a randomized trial (Austin 2011). Here, we matched subjects on a propensity score for living within 250 m of blue space at baseline using a logistic regression model with a matching ratio of 1:2. The covariates entered in the propensity score included age, sex, and all the personal covariates described above, along with population density. We did not match on CMA or the other contextual/environmental variables because matching on upwards of 60 characteristics (including subcategories of categorical variables) limited too greatly the number of potential matches. Subjects who lived within 250 m of water at baseline were matched (as "exposed") to those who did not (as "unexposed") on the logit of the propensity score by using optimal calipers equal to 0.2 of the standard deviation of the logit of the propensity score. We calculated standardized differences for all covariates between cases and controls before and after matching. We examined associations with several of the more common causes mortality among subjects in the resulting matched cohort (i.e., those for which counts of deaths $>2,000$, and thus allowed for sufficient statistical power).

Elsewhere, we reported more protective effects for risk of mortality associated with amount of greenness estimated within 500 m of subjects' residence in comparison with that estimated within 250 m (Crouse et al. 2017). We hypothesized in that case that 500 m might better reflect subjects' daily activity spaces, and we therefore explored survival models here that also considered associations between mortality and blue spaces within 500 m. Additionally, we explored survival models that considered associations between mortality and blue spaces within 1,000 m, for which we hypothesized that we would observe more attenuated or null associations.

Last, we ran fully adjusted lagged models in which exposure was indicated as living within 250 m of water (or not) in the previous year. Follow-up for the lagged models began in 2002; as such, these models are based on a shorter follow-up, and fewer deaths, than are the other models.

Results

Our cohort included approximately 1,265,515 subjects at baseline; 8.3% of whom lived within 250 m of water at baseline (Table 1). Approximately 106,180 subjects died from nonaccidental deaths during the 10.6 y of follow-up; see Table 2 for number deaths by individual causes. The composition of subjects who were and who were not living within 250 m of blue space at baseline were similar. There were more seniors (age 65 and older) among those subjects who were living near water (i.e., 22.4% in comparison with 16.7% among subjects who were not living near water). We found absolute standardized differences between the groups equal to or greater than 10% only for being in the highest income decile (i.e., slightly fewer among those not near blue space); labor force status (i.e., slightly more unemployed or in the labor force among those not near blue spaces); and, neighborhood-level population density and exposure to NO_2 (both slightly lower among those near blue spaces) (Table 2).

We present in Table 3 results of survival models by cause of death according to four levels of covariate adjustment. Adjustment for personal covariates attenuated the associations only slightly, but further adjustments for contextual socioeconomic, and then environmental, covariates produced incrementally more protective associations. In fully adjusted models, we found significant protective associations with all causes of death examined except those

Table 1. Descriptive statistics for cohort subjects at baseline and fully-adjusted hazard ratios (HRs) for nonaccidental mortality for risk factors included in the survival models.

Characteristic	All subjects $n=1{,}265{,}515$ (%)	Subjects living within 250 m of blue space $n=105{,}230$ (%)	Subjects not living within 250 m of blue space $n=1{,}160{,}290$ (%)	Standardized difference	Hazard ratio (95% confidence interval)
Age, in years					
25–64	82.9	77.6	83.3	—	—
65 +	17.1	22.4	16.7	—	—
Sex					
Male	47.3	46.7	47.3	−0.012	—
Female	52.7	53.3	52.7	0.012	—
Visible minority status					
Yes	1.9	1.3	2.0	−0.051	1.00
No	98.1	98.7	98.0	0.051	1.24 (1.16, 1.32)
Aboriginal identity					
Yes	2.0	1.6	2.0	−0.031	1.00
No	98.0	98.4	98.0	0.031	0.68 (0.65, 0.72)
Marital status					
Widowed & not now common law	5.7	7.2	5.6	0.064	1.00
Never married & not now common law	16.3	16.5	16.2	0.007	1.16 (1.13, 1.19)
Common-law	11.9	12.8	11.8	0.031	0.96 (0.93, 1.00)
Legally married & not separated	56.6	53.3	56.9	−0.072	0.81 (0.80, 0.83)
Legally married but separated & not now common law	2.7	2.7	2.7	−0.002	1.12 (1.07, 1.17)
Divorced & not now common law	6.8	7.5	6.7	0.030	1.13 (1.10, 1.16)
Highest level of education					
University undergraduate degree or more	21.5	23.3	21.4	0.046	1.00
Did not complete high school	22.2	23.1	22.1	0.024	1.58 (1.55, 1.62)
Some post-secondary	35.0	33.9	35.1	−0.027	1.35 (1.32, 1.38)
College diploma	21.2	19.7	21.4	−0.041	1.16 (1.13, 1.19)
Income adequacy decile					
1. Lowest	6.6	6.6	6.6	0.002	1.53 (1.48, 1.59)
2.	8.3	8.8	8.3	0.019	1.27 (1.23, 1.31)
3.	9.1	9.0	9.1	−0.003	1.23 (1.19, 1.27)
4.	9.7	9.1	9.8	−0.022	1.17 (1.14, 1.21)
5.	10.3	9.5	10.4	−0.028	1.13 (1.10, 1.17)
6.	10.7	9.9	10.7	−0.028	1.09 (1.05, 1.12)
7.	11.0	10.3	11.1	−0.025	1.08 (1.05, 1.12)
8.	11.3	10.5	11.3	−0.026	1.04 (1.00–1.07)
9.	11.5	11.5	11.5	0.000	1.03 (1.00, 1.07)
10. Highest	11.6	14.7	11.3	0.101	1.00
Labor force status					
Not in labor force	29.8	34.9	29.3	0.121	1.00
Employed	67.1	62.0	67.5	−0.115	0.59 (0.57, 0.60)
Unemployed	3.2	3.1	3.2	−0.008	0.84 (0.80, 0.89)

Note: Hazard ratios (HRs) and 95% confidence intervals for associations between living within 250 m of blue space and non-accidental mortality. Models stratified by age (5-y categories), sex, and census metropolitan area (CMA); adjusted for visible minority status, Aboriginal identity, marital status, highest level of education, income adequacy decile, and labor force status; and also for contextual variables calculated as census division means subtracted from census tract means using data from the most recent census year: % unemployed (age 25 y and older), % not graduated from high school (age 25 y and older), and % low-income status, and population density, $PM_{2.5}$, O_3, NO_2, and residential greenness.

Table 2. Descriptive statistics for contextual characteristics of subjects at baseline.

Characteristic	All subjects mean (standard deviation)	Subjects living within 250 m of blue space mean (standard deviation)	Subjects not living within 250 m of blue space mean (standard deviation)	Standardized difference
Dissemination area-level population density (log(people/km^2))	7.97 (1.05)	7.60 (1.16)	7.99 (1.04)	−0.273
Census Division means subtracted from Census-Tract means				
% unemployed (aged 25 and older)	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	−0.087
% not graduated from high school (aged 25 and older)	−0.01 (0.07)	−0.01 (0.07)	−0.01 (0.07)	0.085
% low income status	−0.01 (0.08)	−0.00 (0.08)	−0.01 (0.08)	0.039
Residential greenness within 250 m (range: 0–1)				
$PM_{2.5}$ (μg/m^3)	9.26 (2.71)	9.09 (2.64)	9.28 (2.72)	−0.070
NO_2 (ppb)	17.87 (7.37)	16.43 (7.12)	18.01 (7.37)	−0.217
O_3 (ppb)	37.69 (6.34)	37.06 (6.70)	37.74 (6.30)	−0.105

deaths from external/accidental causes (i.e., HR for nonaccidental deaths: 0.879; 95% confidence intervals (CIs): 0.861, 0.897); HR for external/accidental deaths = 0.932; 95% CI: 0.847, 1.026). We found the most protective effects for deaths from stroke and respiratory-related diseases.

We present in Figure 2 results of effect modification by selected personal characteristics of subjects at baseline. We found more protective associations among women and among older adults. We observed some suggestion of more protective effects among subjects in the lowest income adequacy deciles in comparison with those in the highest deciles; however, these differences were not statistically significant. We did not observe any evidence for effect modification by educational attainment.

Results of Additional Analyses

We successfully matched all 105,230 subjects who lived within 250 m of blue spaces at baseline with 210,455 subjects who did not. After matching, the absolute standardized differences were less than 5% for all variables entered into the propensity score, confirming adequate matching (Table S1). Using the matched cohort, our results from fully adjusted models for all the causes of death examined were more protective than those reported with the full cohort (i.e., HR for nonaccidental mortality: 0.756; 95% CI: 0.736, 0.776; Table 4). Associations between mortality and blue space estimated within 500 m and 1,000 m were incrementally attenuated in all cases in comparison with those within 250 m (Figure 3). At 500 m, the HR for death from respiratory causes was not just attenuated, but nonsignificant; at 1,000 m, we found significant associations only with nonaccidental, cardiovascular and diabetes, cardiovascular, and ischemic heart disease. Results of the lagged models are presented in Table 5; associations with all causes of death examined were attenuated in comparison with the main models. For example, HR for deaths from nonaccidental causes in the lagged model was 0.950; 95% CI: 0.931, 0.971.

Discussion

This is among the very first studies to examine associations between residential exposures to blue spaces and risks to mortality. In this large, multicity national cohort, we demonstrated strong protective associations between living in close proximity to open water and several common causes of death among adult, nonimmigrant, urban Canadians. We also did not observe association with a negative control (accidental mortality), and we used a propensity score matched cohort analysis to further eliminate potential confounding by baseline characteristics between exposed and unexposed subjects, which was a study design that produced even stronger evidence of a protective association. We found evidence of protective associations among subjects across all income groups, which suggests that the effects observed are not due simply to more affluent people being able to afford to live near water.

As noted earlier, the only other published study to consider the potential link between mortality and blue space reported that living within 4 km of water was associated with decreased heat-related mortality (in comparison with living beyond that) among elderly

Table 3. Hazard ratios and 95% confidence intervals for associations between cause-specific mortality and living within 250 m of water.

Cause of death (counts rounded to nearest 5)	Unadjusted[a]	Adjusted: individual covariates[b]	Adjusted: individual + ecological covariates[c]	Fully adjusted[d]
Non-accidental ($n = 106,180$)	0.882 (0.864, 0.900)	0.903 (0.885, 0.922)	0.896 (0.878, 0.914)	0.879 (0.861, 0.897)
Cardiovascular and diabetes ($n = 34,005$)	0.857 (0.827, 0.889)	0.880 (0.849, 0.913)	0.873 (0.842, 0.906)	0.854 (0.823, 0.886)
Cardiovascular ($n = 30,855$)	0.862 (0.830, 0.895)	0.883 (0.850, 0.918)	0.875 (0.842, 0.909)	0.855 (0.822, 0.888)
Ischemic heart disease ($n = 17,885$)	0.870 (0.828, 0.915)	0.896 (0.852, 0.942)	0.886 (0.842, 0.932)	0.869 (0.826, 0.914)
Cerebrovascular disease ($n = 5,955$)	0.853 (0.783, 0.931)	0.868 (0.796, 0.947)	0.861 (0.790, 0.939)	0.834 (0.765, 0.910)
Respiratory ($n = 9,465$)	0.831 (0.776, 0.891)	0.859 (0.802, 0.921)	0.853 (0.796, 0.914)	0.838 (0.782, 0.898)
Dementia and Alzheimer's disease ($n = 5,595$)	0.891 (0.818, 0.970)	0.899 (0.826, 0.979)	0.884 (0.812, 0.963)	0.854 (0.784, 0.930)
External/accidental ($n = 5,240$)	0.945 (0.859, 1.038)	0.951 (0.865, 1.046)	0.940 (0.855, 1.034)	0.932 (0.847, 1.026)

[a]Stratified by age (5-y categories), sex, and census metropolitan area (CMA).
[b]Same as [a]; adjusted for visible minority status, Aboriginal status, marital status, educational attainment, income adequacy decile, and labor force status.
[c]Same as [b]; adjusted also for contextual variables calculated as census-division means subtracted from census-tract means using data from the most recent census year: % unemployed (age 25 y and older), % not graduated from high school (age 25 y and older), and % low income status, and also for dissemination area-level population density.
[d]Same as [c]; adjusted also for $PM_{2.5}$, O_3, NO_2, and residential greenness.

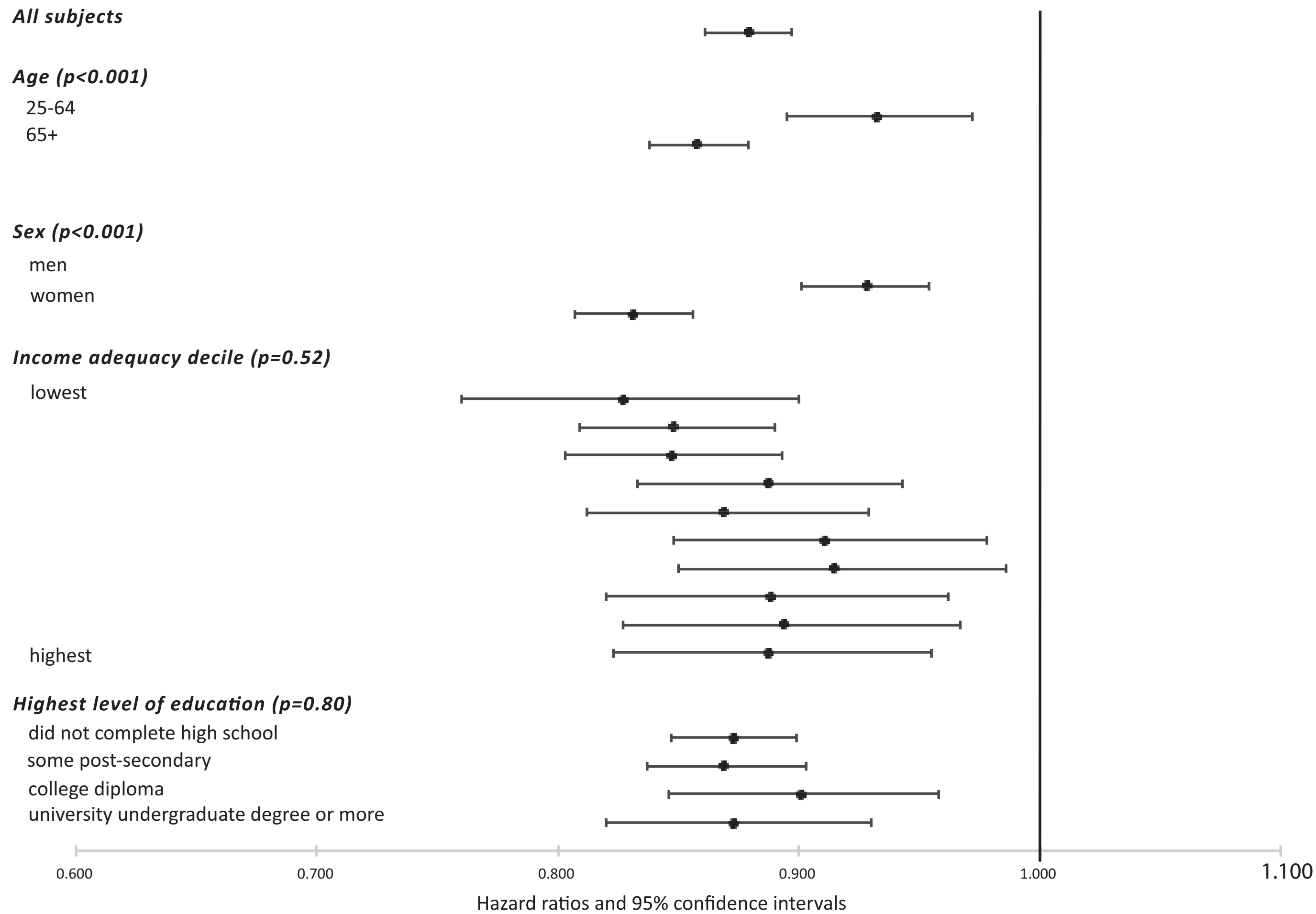

Figure 2. Hazard ratios and 95% confidence intervals from fully adjusted models for mortality from nonaccidental deaths and living within 250 m of water, and effect modification by selected characteristics. Note: Models stratified by age (5-y categories), sex, and census metropolitan area (CMA); adjusted for visible minority status, Aboriginal identity, marital status, highest level of education, income adequacy decile, and labor force status; and also for contextual variables calculated as census division means subtracted from census tract means using data from the most recent census year: % unemployed (age 25 y and older), % not graduated from high school (age 25 y and older), and % low-income status, and population density, $PM_{2.5}$, O_3, NO_2, and residential greenness. *P*-values for Q-statistic (test for effect modification).

subjects in Lisbon (Burkart et al. 2016). In the absence of other studies on blue space with which to compare our results, we note that our associations with deaths from nonaccidental causes were stronger than those reported elsewhere with estimates of residential greenness (Crouse et al. 2017; James et al. 2016; Vienneau et al. 2017; Villeneuve et al. 2012). We found more protective effects among women and among older subjects. In our earlier study with this cohort, we found more protective effects from exposures to

Table 4. Hazard ratios and 95% confidence intervals for associations between cause-specific mortality and living within 250 m based on the matched cohort analysis.

Cause of death (counts rounded to nearest 5)	Fully adjusted[a]
Non-accidental ($n = 33{,}295$)	0.756 (0.736, 0.776)
Cardiovascular and diabetes ($n = 10{,}915$)	0.724 (0.691, 0.759)
Cardiovascular ($n = 9{,}955$)	0.25 (0.791, 0.762)
Ischemic heart disease ($n = 5{,}665$)	0.737 (0.691, 0.786)
Respiratory ($n = 3{,}035$)	0.718 (0.657, 0.785)

[a]Models stratified by age (5-y categories), sex, and census metropolitan area (CMA); adjusted for visible minority status, Aboriginal identity, marital status, highest level of education, income adequacy decile, and labor force status; and for contextual variables calculated as census division means subtracted from census tract means using data from the most recent census year: % unemployed (age 25 y and older), % not graduated from high school (age 25 y and older), and % low income status, and population density, $PM_{2.5}$, O_3, NO_2, and residential greenness.

residential greenness among men and among those who were more affluent and better educated (Crouse et al. 2017). Results of effect modification by gender, sex, age, and income in the context of exposures to natural environments and health broadly have been inconsistent in the existing literature (Gascon et al. 2017; Markevych et al. 2017; van den Berg et al. 2015). Possible explanations that have been suggested for gender differences in the associations between health and natural environments (green or blue) are differences in perceptions and usage of nature between women and men. As no other studies on the relation between blue space and mortality exist, more research is needed to confirm any consistent gender differences. As noted earlier, although most previous studies suggest a positive relationship between blue-space exposure and health, there has been some inconsistency in the results. Our study is comparatively large (much of the existing literature relied on small sample sizes) and uses a design that minimizes self-selection bias, which supports the validity of our results.

It is important to understand that for the most part, our exposure metric captures potential *views* of *or passive exposures* to blue spaces, though not necessarily capturing time spent *on* or *interacting* with blue spaces (e.g., at a beach or on a boat). A related limitation of our study is that we were unable to account for access or exposures to blue spaces outside subjects' primary

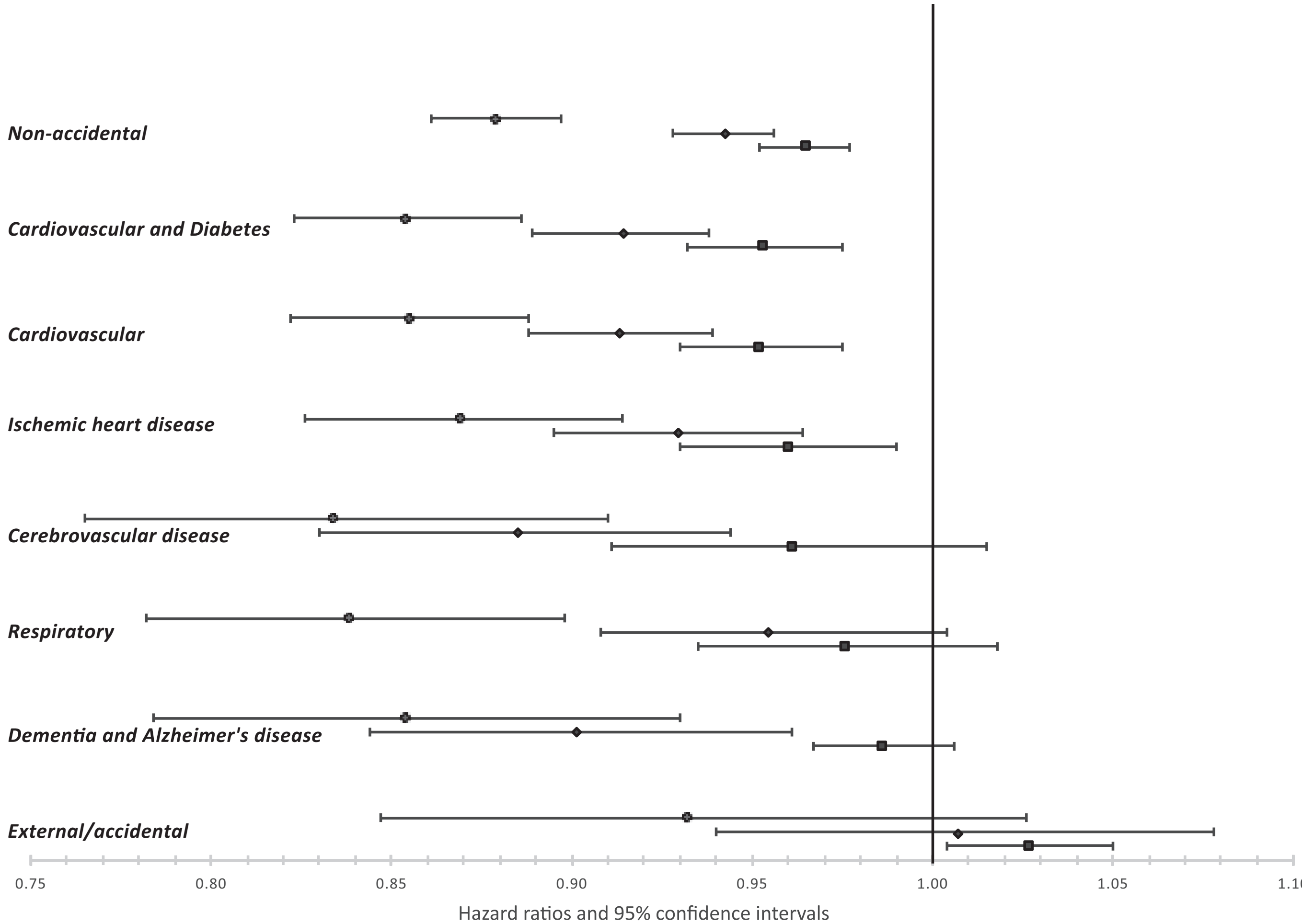

Figure 3. Hazard ratios and 95% confidence intervals from fully adjusted models for mortality and living within 250 m, 500 m, and 1,000 m of water. Circle = associations within 250 m; diamond = associations within 500 m; square = associations within 1,000 m. Note: [Circle equals associations] within [250 meters]; [diamond equals associations] within [500 meters]; [square equals associations] within [1,000 meters]. Models stratified by age (5-y categories), sex, and census metropolitan area (CMA); adjusted for visible minority status, Aboriginal identity, marital status, highest level of education, income adequacy decile, and labor force status; and also for contextual variables calculated as census division means subtracted from census tract means using data from the most recent census year: % unemployed (age 25 y and older), % not graduated from high school (age 25 y and older), and % low income status, and population density, $PM_{2.5}$, O_3, NO_2, and residential greenness.

residence (for example, time spent at recreational properties). As such, similar to what has been reported elsewhere with views of nature from the home (Kaplan 2001), our results further suggest that the restorative benefits associated with just having a view of blue space from the home or during regular routine activities in the vicinity with passive exposures may contribute to various aspects of health and well-being. Proximity to blue space, and its attendant reduced exposure to a variety of urban stressors (psychosocial, chemical, physical) and greater exposure to health-promoting factors and behaviors, may confer net beneficial effects on physiological systems that integrate stress response. Supporting this contention, residing near natural spaces (urban green space) is associated with significantly lower levels of biomarkers of physiological dysregulation (Egorov et al. 2017) that predict mortality risk (Seeman et al. 2001). It has been estimated that Canadian adults spend approximately 65% of their daily time at home (indoors and outdoors combined), so residential exposures account for a substantial portion of total daily exposures (Leech et al. 2002). Older and retired people likely spend more time around their homes and therefore have increased opportunities for exposures to residential blue spaces, which may contribute to explaining the stronger effects observed among older subjects.

We further examined the potential for residual confounding by using a propensity-matched cohort and observed more protective associations in all cases than with the full cohort. Among subjects in the matched cohort, those living within and beyond 250 m of water were more similar to each other in terms of age

Table 5. Hazard ratios and 95% confidence intervals for associations between cause-specific mortality and living within 250 m of water in the previous year (i.e., lagged models).

Cause of death (counts rounded to nearest 5)	Fully adjusted[a]
Nonaccidental ($n = 96,650$)	0.950 (0.931, 0.971)
Cardiovascular and diabetes ($n = 30,765$)	0.917 (0.883, 0.952)
Cardiovascular ($n = 27,880$)	0.916 (0.881, 0.953)
Ischemic heart disease ($n = 16,075$)	0.936 (0.889, 0.986)
Cerebrovascular disease ($n = 5,395$)	0.887 (0.811, 0.971)
Respiratory ($n = 8,710$)	0.923 (0.860, 0.990)
Dementia and Alzheimer's disease ($n = 5,355$)	0.832 (0.761, 0.908)
External/accidental ($n = 4,690$)	1.033 (0.937, 1.139)

[a]Models stratified by age (5-y categories), sex, and census metropolitan area (CMA); adjusted for visible minority status, Aboriginal identity, marital status, highest level of education, income adequacy decile, and labor force status; and also for contextual variables calculated as census division means subtracted from census tract means using data from the most recent census year: % unemployed (age 25 y and older), % not graduated from high school (age 25 y and older), and % low income status, and population density, $PM_{2.5}$, O_3, NO_2, and residential greenness.

distribution, marital status, proportion in the highest income decile, and neighborhood-level population density (than were those living within and beyond 250 m in the full cohort; Table S1). Unfortunately, however, the number of deaths for several outcomes (i.e., stroke, dementia, accidental) was very low in this cohort, such that we lacked the statistical power to assess any association between living near blue spaces and these causes of death.

Associations between risks of mortality and estimates of blue space within 500 m and 1,000 m were notably attenuated in comparison with those within 250 m. Although those larger buffers may represent typical neighborhood activity spaces better for many people, blue spaces at this distance from one's home would almost certainly not be visible or within audible range and may also not contribute as significant cooling benefits during high heat events.

Associations between risks of mortality and lagged estimates of blue space were also attenuated. Given the limited research on this topic, relevant exposure periods and potential dose–response relationships remain unknown. The results of these models are useful because they introduce a note of caution, in that we cannot discount the possibility that our findings could be influenced by movement of people into or out of blue space areas according to their health status. These more attenuated associations may also be due to chance.

A key strength of our study is the large, broadly representative nature of this multicity national cohort. Subjects were drawn from cities across the entire country, including some located along ocean coastlines, others located on major lakes and rivers, and others with no major local water features. We stratified our survival models by age, sex, and CMA, such that subjects were compared statistically only with others living in the same cities, and thus also in areas with similar climates, and with relatively similar access to health, social, and other services. We were able to track subjects' residential mobility patterns with annual postal codes, which have high positional accuracy in urban areas, thus minimizing exposure misclassification. Another key strength of this study is that, in addition to many personal and community socioeconomic characteristics, we were able to adjust our survival models also for other urban environmental exposures, including ambient air pollution and residential greenness (but we did lack information on noise, which is a potentially harmful urban exposure that we would expect to be negatively correlated with blue space).

To validate our findings, we presented null associations between mortality from external/accidental causes and blue space exposures. Although these null associations met our hypothesized expectation, these results should be treated with caution, given the relatively small number of deaths ($n = \sim 5{,}000$).

A limitation of our exposure metric is that it indicates only that subjects live relatively near to blue space, but it does not capture the accessibility or quality of these spaces. We acknowledge that the sounds, smells, and sights associated with being near the ocean are very different from the those of the experience of being near a small, interior lake. Moreover, assuming that prevailing winds come from the west, the east shore of a larger water surface would experience a greater cooling effect than would the west. In this context, future studies may wish to explore whether associations differ depending on the size or other characteristics of the available blue space. The accessibility of the blue spaces may have limited influence on some health outcomes, as benefits to health associated with their sounds and cooling effects would be achieved regardless.

Conclusions

Our findings contribute to the growing body of evidence suggesting that everyday exposures to natural environments in urban areas have important benefits to health, which may be attributed to a range of passive/active, intentional/incidental exposures, and direct/indirect pathways. Further work is needed, however, to understand better the various potential drivers of this association.

Acknowledgments

D.L.C. and A.B. were supported by the Maritime SPOR Support Unit (MSSU), which receives financial support from the Canadian Institutes of Health Research (CIHR), the Nova Scotia Department of Health and Wellness, the New Brunswick Department of Health, the Nova Scotia Health Research Foundation (NSHRF), and the New Brunswick Health Research Foundation (NBHRF). The opinions, results, and conclusions reported in this paper are those of the authors and are independent from the funding sources. No endorsement by the MSSU or the named funding partners is intended or should be inferred.

The analysis presented in this paper was conducted at the New Brunswick Research Data Centre, which is part of the Canadian Research Data Centre Network (CRDCN). The services and activities provided by the New Brunswick Research Data Centre are made possible by the financial or in-kind support of the SSHRC, the CIHR, the CFI, Statistics Canada, and the University of New Brunswick. The views expressed in this paper do not necessarily represent those of the CRDCN or that of its partners.

References

Annerstedt M, Jönsson P, Wallergård M, Johansson G, Karlson B, Grahn P. 2013. Inducing physiological stress recovery with sounds of nature in a virtual reality forest–results from a pilot study. Physiol Behav 118:240–250, PMID: 23688947, https://doi.org/10.1016/j.physbeh.2013.05.023.

Austin PC. 2011. An introduction to propensity score methods for reducing the effects of confounding in observational studies. Multivariate Behav Res 46(3):399–424, PMID: 21818162, https://doi.org/10.1080/00273171.2011.568786.

Axelson O. 1980. Aspects of confounding and effect modification in the assessment of occupational cancer risk. J Toxicol Environ Health 6(5–6):1127–1131, PMID: 7463507, https://doi.org/10.1080/15287398009529933.

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS. 2010a. Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landsc. Urban Plan 97(3):147–155, https://doi.org/10.1016/j.landurbplan.2010.05.006.

Bowler DE, Buyung-Ali LM, Knight TM, Pullin AS. 2010b. A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 10:456, PMID: 20684754, https://doi.org/10.1186/1471-2458-10-456.

Brereton F, Clinch JP, Ferreira S. 2008. Happiness, geography and the environment. Ecol Econ 65(2):386–396, https://doi.org/10.1016/j.ecolecon.2007.07.008.

Burkart K, Meier F, Schneider A, Breitner S, Canário P, Alcoforado MJ, et al. 2016. Modification of heat-related mortality in an elderly urban population by vegetation (urban green) and proximity to water (urban blue): evidence from Lisbon, Portugal. Environ Health Perspect 124(7):927–934., PMID: 26566198, https://doi.org/10.1289/ehp.1409529.

Crouse D, Pinault L, Balram A, Hystad P, Peters P, Chen H, et al. 2017. Urban greenness and mortality in Canada's largest cities: a national cohort study. Lancet Planet Health 1(7):e289–e297, PMID: 29851627, https://doi.org/10.1016/S2542-5196(17)30118-3.

Crouse DL, Peters PA, Hystad P, Brook JR, van Donkelaar A, Martin RV, et al. 2015. Ambient PM2.5, O_3, and NO_2 exposures and associations with mortality over 16 years of follow-up in the Canadian census health and environment cohort (CanCHEC). Environ Health Perspect 123(11):1180–1186, PMID: 26528712, https://doi.org/10.1289/ehp.1409276.

de Vries S, van Dillen SME, Groenewegen PP, Spreeuwenberg P. 2013. Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Soc Sci Med 94:26–33, PMID: 23931942, https://doi.org/10.1016/j.socscimed.2013.06.030.

Egorov AI, Griffin SM, Converse RR, Styles JN, Sams EA, Wilson A, et al. 2017. Vegetated land cover near residence is associated with reduced allostatic load and improved biomarkers of neuroendocrine, metabolic and immune functions. Environ Res 158:508–521, PMID: 28709033, https://doi.org/10.1016/j.envres.2017.07.009.

Gascon M, Sánchez-Benavides G, Dadvand P, Martínez D, Gramunt N, Gotsens X, et al. 2018. Long-term exposure to residential green and blue spaces and anxiety and depression in adults: a cross-sectional study. Environ Res 162:231–239, PMID: 29358115, https://doi.org/10.1016/j.envres.2018.01.012.

Gascon M, Zijlema W, Vert C, White MP, Nieuwenhuijsen MJ. 2017. Outdoor blue spaces, human health and well-being: a systematic review of quantitative studies. Int J Hyg Environ Health 220(8):1207–1221, https://doi.org/10.1016/j.ijheh.2017.08.004.

Glazer KB, Eliot MN, Danilack VA, Carlson L, Phipps MG, Dadvand P, et al. 2018. Residential green space and birth outcomes in a coastal setting. Environ Res 163:97–107, PMID: 29433021, https://doi.org/10.1016/j.envres.2018.01.006.

Hartig T, Mitchell R, de Vries S, Frumkin H. 2014. Nature and health. Annu Rev Public Health 35(1):207–228, PMID: 24387090, https://doi.org/10.1146/annurev-publhealth-032013-182443.

Hystad P, Setton E, Cervantes A, Poplawski K, Deschenes S, Brauer M, et al. 2011. Creating national air pollution models for population exposure assessment in Canada. Environ Health Perspect 119(8):1123–1129, PMID: 21454147, https://doi.org/10.1289/ehp.1002976.

James P, Hart J, Banay R, Laden F. 2016. Exposure to greenness and mortality in a nationwide prospective cohort study of women. Environ Health Perspect 124(9):1344–1352, PMID: 27074702, https://doi.org/10.1289/ehp.1510363.

Kaplan R. 2001. The nature of the view from home: psychological benefits. Environ Behav 33(4):507–542, https://doi.org/10.1177/00139160121973115.

Leech JA, Nelson WC, Burnett RT, Aaron S, Raizenne ME. 2002. It's about time: a comparison of Canadian and American time-activity patterns. J Expo Anal Environ Epidemiol 12(6):427–432, PMID: 12415491, https://doi.org/10.1038/sj.jea.7500244.

Livesley SJ, McPherson GM, Calfapietra C. 2016. The urban forest and ecosystem services: impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. J Environ Qual 45(1):119–124, PMID: 26828167, https://doi.org/10.2134/jeq2015.11.0567.

Markevych I, Schoierer J, Hartig T, Chudnovsky A, Hystad P, Dzhambov AM, et al. 2017. Exploring pathways linking greenspace to health: theoretical and methodological guidance. Environ Res 158:301–317, PMID: 28672128, https://doi.org/10.1016/j.envres.2017.06.028.

Ng E. 2011. The healthy immigrant effect and mortality rates. Health Rep 22(4):25–29, PMID: 22352149.

Nowak DJ, Hirabayashi S, Bodine A, Greenfield E. 2014. Tree and forest effects on air quality and human health in the United States. Environ Pollut 193:119–129, PMID: 25016465, https://doi.org/10.1016/j.envpol.2014.05.028.

Nutsford D, Pearson AL, Kingham S, Reitsma F. 2016. Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. Heal Place 39:70–78, PMID: 26974233, https://doi.org/10.1016/j.healthplace.2016.03.002.

Pinault L, Fines P, Labrecque-Synnott F, Saidi A, Tjepkema M. 2016. The 2001 Canadian Census-Tax-Mortality cohort: a 10-year follow-up. Analytical Studies: Methods and References Cat. No. 11-633-X, no.003.

Pinault L, Weichenthal S, Crouse DL, Brauer M, Erickson A, van Donkelaar A et al. 2017. Associations between fine particulate matter and mortality in the 2001 Canadian Census Health and Environment Cohort (2001 CanCHEC). Environ Res 159:406–415, PMID: 28850858, https://doi.org/10.1016/j.envres.2017.08.037.

Robichaud A, Ménard R. 2014. Multi-year objective analyses of warm season ground-level ozone and $PM_{2.5}$ over North America using real-time observations and Canadian operational air quality models. Atmos Chem Phys 14(4):1769–1800, https://doi.org/10.5194/acp-14-1769-2014.

Rook GA. 2013. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. Proc Natl Acad Sci USA 110(46):18360–18367, PMID: 24154724, https://doi.org/10.1073/pnas.1313731110.

Sallis JF, Cerin E, Conway TL, Adams MA, Frank LD, Pratt M, et al. 2016. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. Lancet 387(10034):2207–2217, PMID: 27045735, https://doi.org/10.1016/S0140-6736(15)01284-2.

Schindler DW. 2009. Lakes as sentinels and integrators for the effects of climate change on watersheds, airsheds, and landscapes. Limnol Oceanogr 54(6part2):2349–2358, https://doi.org/10.4319/lo.2009.54.6_part_2.2349.

Seeman TE, McEwen BS, Rowe JW, Singer BH. 2001. Allostatic load as a marker of cumulative biological risk: MacArthur studies of successful aging. Proc Natl Acad Sci USA 98(8):4770–4775, PMID: 11287659, https://doi.org/10.1073/pnas.081072698.

Statistics Canada. 2011. Boundary Files, Reference Guide, 1st ed. 2011 Census. Catalogue no. 92-160-G. Ottawa, Ontario:Statistics Canada.

van den Berg M, Wendel-Vos W, van Poppel M, Kemper H, van Mechelen W, Maas J. 2015. Health benefits of green spaces in the living environment: a systematic review of epidemiological studies. Urban For Urban Green 14(4):806–816, https://doi.org/10.1016/j.ufug.2015.07.008.

van den Bosch M, Ode Sang Å. 2017. Urban natural environments as nature-based solutions for improved public health – a systematic review of reviews. Environ Res 158:373–384, PMID: 28686952, https://doi.org/10.1016/j.envres.2017.05.040.

van Donkelaar A, Martin RV, Spurr RJD, Burnett RT. 2015. High-resolution satellite-derived PM2.5 from optimal estimation and geographically weighted regression over North America. Environ Sci Technol 49(17):10482–10491, PMID: 26261937, https://doi.org/10.1021/acs.est.5b02076.

Vienneau D, de Hoogh K, Faeh D, Kaufmann M, Wunderli JM, Röösli M. 2017. More than clean air and tranquillity: residential green is independently associated with decreasing mortality. Environ Int 108:176–184, PMID: 28863390, https://doi.org/10.1016/j.envint.2017.08.012.

Villeneuve PJ, Jerrett M, Su JG, Burnett RT, Chen H, Wheeler AJ, et al. 2012. A cohort study relating urban green space with mortality in Ontario, Canada. Environ Res 115:51–58, PMID: 22483437, https://doi.org/10.1016/j.envres.2012.03.003.

Völker S, Heiler A, Pollmann T, Claßen T, Hornberg C, Kistemann T. 2018. Do perceived walking distance to and use of urban blue spaces affect self-reported physical and mental health? Urban For Urban Green 29:1–9, https://doi.org/10.1016/j.ufug.2017.10.014.

Völker S, Kistemann T. 2013. 'I'm always entirely happy when I'm here!' Urban blue enhancing human health and well-being in Cologne and Düsseldorf, Germany. Soc Sci Med 78:113–124, PMID: 23273410, https://doi.org/10.1016/j.socscimed.2012.09.047.

Völker S, Kistemann T. 2011. The impact of blue space on human health and well-being - salutogenetic health effects of inland surface waters: a review. Int J Hyg Environ Health 214(6):449–460, PMID: 21665536, https://doi.org/10.1016/j.ijheh.2011.05.001.

White M, Smith A, Humphryes K, Pahl S, Snelling D, Depledge M. 2010. Blue space: the importance of water for preference, affect, and restorativeness ratings of natural and built scenes. J Environ Psychol 30(4):482–493, https://doi.org/10.1016/j.jenvp.2010.04.004.