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by **Nicholas Lantz, Marcelle Grenier** and **Jennie Wang**

Green spaces are essential to building the resilience and liveability of cities through the ecosystem goods and services they provide. For example, trees and other vegetation can improve urban air quality, mitigate urban heat island effects, reduce or delay storm water runoff, provide wildlife habitat and provide recreational opportunities and aesthetic benefits.[1]

Urban greenness reflects the presence and health of vegetation in urban areas and is a measure of urban ecosystem condition. This study uses data from satellite imagery to track greenness across cities at three points in time. These data broadly represent vegetation across the whole of the city, reflecting parks and other publicly and privately owned green spaces and features. The level of urban greenness will depend on natural environmental conditions, for example climate, as well as differences in local land use.[2]

Urbanization processes such as densification and urban expansion can result in significant reductions in the quantity and quality of 'green' areas and related increases in 'grey' areas that consist of buildings, impervious surfaces, bare soil and low density vegetation. Long-term and temporary changes in greenness can be linked to these urbanization processes, as well as the addition or maturing of urban vegetation and changes in vegetation condition related to natural factors such as drought, insects or disease.

Note to readers

This analysis provides a synoptic view of urban greenness in Canada for three reference years over an 18-year period as a measure of urban condition. For more information on ecosystem accounts, see Canadian System of Environmental-Economic Accounting – Ecosystem Accounts. This assessment provides a consistent approach for measuring urban greenness across the country, which can be used to help measure progress towards the United Nations Sustainable Development Goal 11 target 11.7 "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces."[3] Monitoring greenness over time can help inform decision making on greening policies.

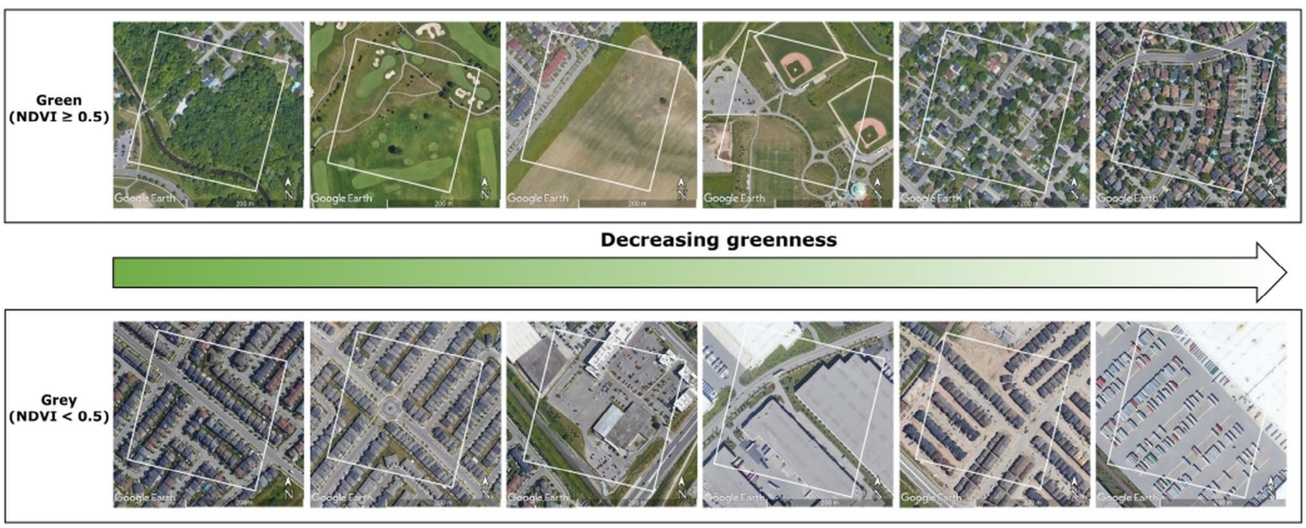
This analysis used the normalized difference vegetation index (NDVI) generated from moderate resolution imaging spectroradiometer (MODIS)[4] to estimate average urban greenness for 996 of 1,010 population centres (i.e., those located south of 60° latitude) in summer.[5] In short, NDVI was used to measure the overall greenness of cities and towns in Canada.

NDVI captured by remote sensors is an indicator of vegetation presence and quantity—it provides a relative measure of photosynthetic activity. The results of NDVI calculation range from -1 to +1 and these values vary depending on the type of satellite images, season, study area, atmospheric effects, soil type, humidity, etc. Generally, high NDVI values correspond to healthier vegetation while low NDVI values indicate less or no vegetation. NDVI values close to +1 should represent dense green leaves, whereas very low values (0.1 and below) correspond to barren rock, sand, snow, water or impervious surfaces (e.g., roads and buildings).

1. European Commission, 2016, "Urban ecosystems," *Mapping and Assessment of Ecosystems and their Services*, 4th report, https://ec.europa.eu/environment/nature/knowledge/ecosystem_assessment/pdf/102.pdf (accessed September 18, 2020); Heris, M., et al., 2021, "Piloting urban ecosystem accounting for the United States," *Ecosystem Services,* Vol. 48, https://doi.org/10.1016/j.ecoser.2020.101226 (accessed February 1, 2021).
2. Nowak, D. J., et al., 1996, "Measuring and analyzing urban tree cover," *Landscape and Urban Planning,* Vol. 36, no. 1, https://doi.org/10.1016/S0169-2046(96)00324-6 (accessed September 18, 2020).
3. Corbane et al. (2020) have proposed greenness, as measured using NDVI, as a proxy indicator to measure progress towards SDG target 11.7. For more information, see Corbane, C., et al., 2020, "The grey-green divide: multi-temporal analysis of greenness across 10,000 urban centres derived from the Global Human Settlement Layer (GHSL)," *International Journal of Digital Earth,* 2020, Vol. 13, no. 1, p. 101-118, https://doi.org/10.1080/17538947.2018.1530311 (accessed September 21, 2020).
4. Statistics Canada, 2019, Corrected representation of the NDVI using historical MODIS satellite images (250 m resolution) from 2000 to 2019, (https://open.canada.ca/data/en/dataset/dc700f75-19d8-4913-9846-78615ca93784 (accessed September 18, 2020); Bédard, F., 2010, "Satellite image data processing at Statistics Canada for the Crop Condition Assessment Program (CCAP)," *Methodology document for Statistics Canada Integrated Metadata base,* https://www.statcan.gc.ca/eng/statistical-programs/document/5177_D1_T9_V1 (accessed September 18, 2020); Davidson, A., 2018, *An Operational Canadian Ag-Land Monitoring System (CALMS): Near-real-time agricultural assessment from space*, Agriculture and Agri-Food Canada, 100 pp.
5. Population centres have a population of at least 1,000 and a population density of 400 persons or more per square kilometre, based on population counts from the Census of Population. All areas outside population centres are classified as rural areas. Population centres are classified in three groups: small (population between 1,000 and 29,999), medium (population between 30,000 and 99,999) and large urban (100,000 or more). Ottawa-Gatineau, Lloydminster, Hawkesbury, Campbellton and Flin Flon have been split at the provincial boundaries. For more information see the Census Dictionary (accessed November 12, 2020).

The urban green class defined in this analysis corresponds to areas with an NDVI greater than or equal to 0.5, representing areas that are predominantly vegetated (Figure 1). Areas with lower values are considered 'grey' and are largely non-vegetated, though patches of grass, shrubs or crops, or other unhealthy/poor condition vegetation will be included. The selection of the 0.5 cut-off for identifying green and grey areas was determined after analysis of more than 50 sites using high resolution imagery available in Google Earth Pro and ESRI imagery basemaps and the application of the NDVI trends and vegetation change tools available in Google Earth Engine. The greenness layers and changes were also compared visually to the urban greenness score assigned by Czekajlo et al. for 10 sites.[6] The areas showing decrease of greenness were similar on both products. Water areas were excluded from the analysis.

Figure 1
Examples of urban pixels classed as green or grey



Note: The green or grey class is based on the MODIS NDVI value.

Greenness was assessed for nine weeks from June 25 to August 26 for the reference years 2001, 2011 and 2019 for the same physical area using the 2016 population centre boundary to ensure consistency. This geography was developed by Statistics Canada in 2011 to replace the 'urban area' geography and delineation rules were revised for the 2016 Census. Consequently, in this study, the 2001 and 2011 assessments may capture peri-urban areas that were subsequently developed, while 2019 may exclude urban expansion that occurred post 2016. Using the 2016 boundary may therefore bias results towards a higher proportion of green area in 2001 and 2011 and less in 2019.

The MODIS data used in this study has a spatial resolution of 230 m, which corresponds to an area of 0.05 km^2 (i.e., a 52,900 m^2 footprint) and the resolution of the pixel (230 m x 230 m) is a limitation of this data set. However, MODIS vegetation indices have demonstrated the capacity to identify spatial and temporal patterns of human growth in urban areas.[7] MODIS NDVI is often used in epidemiological investigations of greenness and health,[8] and some benefits include its higher temporal resolution compared to the higher spatial resolution sensors, such as Landsat. Similar results have been obtained from MODIS and Landsat NDVI, demonstrating the validity of the MODIS dataset in greenness-health studies.[9] As well, use of MODIS data makes it feasible to collect and process at the continental level.

6. Czekajlo, A. et al., 2020, "The urban greenness score: A satellite-based metric for multi-decadal characterization of urban land dynamics," *International Journal of Applied Earth Observation and Geoinformation,* Vol. 93, https://doi.org/10.1016/j.jag.2020.102210 (accessed November 12, 2020).
7. Hussein, S.O., F. Kovacs and Z. Tobak, 2017, "Spatiotemporal assessment of vegetation indices and land cover for Erbil city and its surrounding using MODIS imageries," *Journal of Environmental Geography*, Vol. 10 (1-2), p. 31-39, https://doi.org/10.1515/jengeo-2017-0004 (accessed November 12, 2020).
8. Crouse, D.L. et al., 2017, "Urban greenness and mortality in Canada's largest cities: a national cohort study," *The Lancet Planetary Health,* Vol 1, no. 7, https://www.sciencedirect.com/science/article/pii/S2542519617301183?via%3Dihub#cesec20 (accessed November 12, 2020); James, P., J.E. Hart, R.F. Banay and F. Laden, 2016, "Exposure to greenness and mortality in a nationwide prospective cohort study of women," *Environmental Health Perspectives,* Vol. 124, no. 9, p. 1344–1352; http://dx.doi.org/10.1289/ehp.1510363 (accessed November 12, 2020); Casey, J.A., et al., 2016, "Greenness and birth outcomes in a range of Pennsylvania communities," *International Journal of Environmental Research and Public Health,* Vol. 13, no. 3, https://doi.org/10.3390/ijerph13030311 (accessed November 12, 2020); Cusack, L., A. Larkin, S. Carozza and P. Hystad, 2017, "Associations between residential greenness and birth outcomes across Texas," *Environmental Research,* Vol. 152, p. 88–95, https://doi.org/10.1016/j.envres.2016.10.003 (accessed November 12, 2020).
9. Reid C.E., L.D. Kubzansky, J. Li, J.L. Shmool and J.E. Clougherty, 2018, "It's not easy assessing greenness: A comparison of NDVI datasets and neighborhood types and their associations with self-rated health in New York City," *Health and Place,* Vol. 54, p. 92-101, https://doi.org/10.1016/j.healthplace.2018.09.005 (accessed November 12, 2020).

This assessment of greenness has several limitations associated with the use of NDVI to represent greenness, including the coarse resolution of the MODIS data and the selection of the 0.5 NDVI cut-off as a threshold to classify green or grey pixels. As well, no distinction was made between greenness resulting from publicly accessible parks and private inaccessible spaces. For trend analysis, assessment of additional time series data is required, while higher resolution data is needed for the identification of detailed urban green spaces. A next step for this work will be the assessment of green space extent and greenness condition using more spatially-detailed datasets and additional time periods.

Greenness lowest in large urban population centres

In 2019, 76% of the area in 996 population centres in southern Canada could be classed as green (Table 1). This percentage varied based on city size and regional differences.

In large urban population centres, an average of 70% of the total land area was classed as green, with the share ranging from 38% in Winnipeg to 94% in Kanata (Chart 1). These values reflect peak summer greenness and can vary greatly depending on local climate conditions. A comparison of the top five large urban population centres shows that 65% of Toronto, 70% of Montreal, 68% of Vancouver, 42% of Calgary and 60% of Edmonton were classed as green in 2019 (Figure 2).

Average urban greenness was 78% for medium population centres and 87% in small population centres. In over one-third (35%) of small population centres the entire area was classed as green. Population centres across the Prairies had the lowest greenness on average. Greenness was highest in the Atlantic provinces.

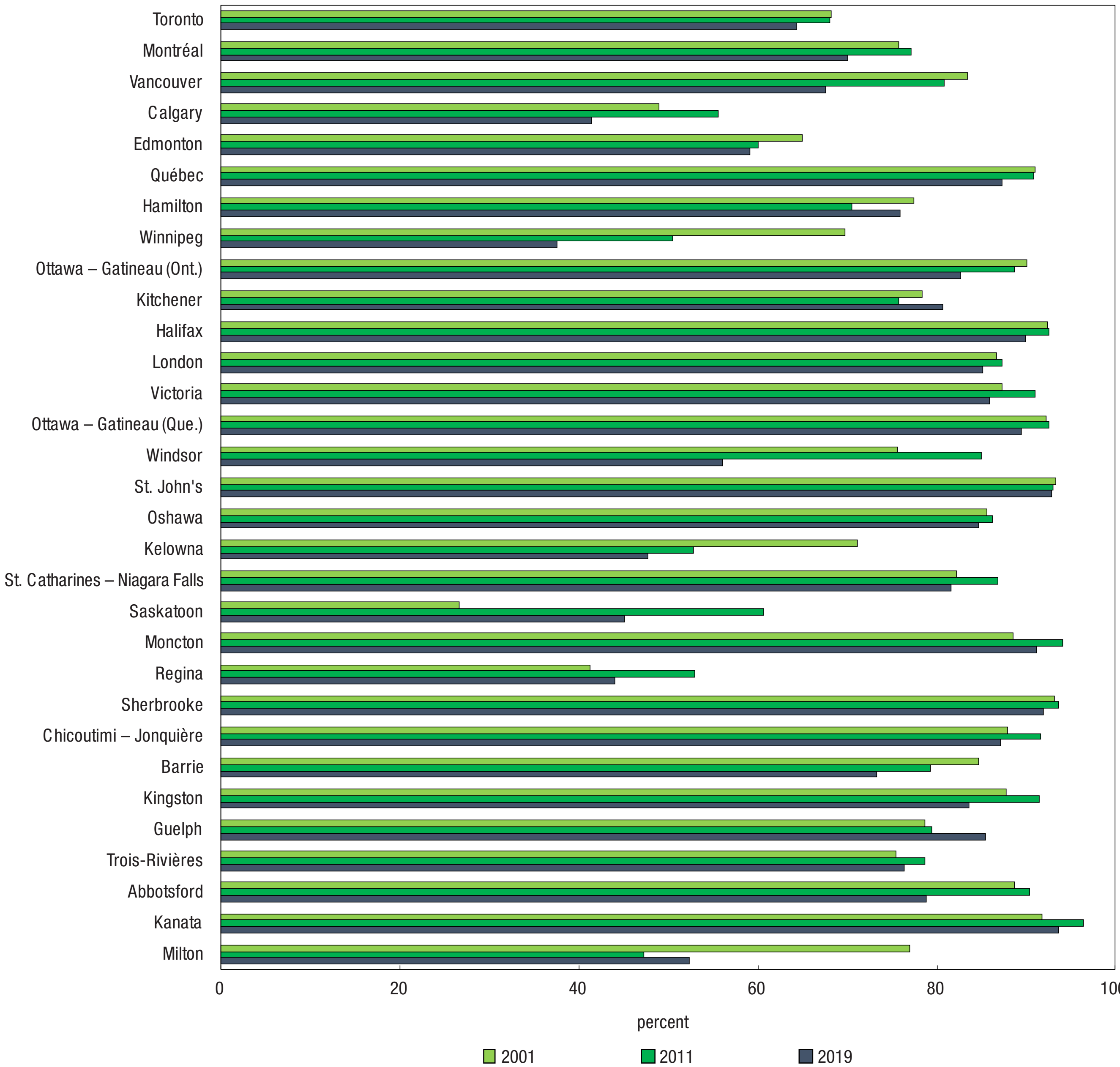
Table 1
Average urban greenness, by population centre size class and region, 2001, 2011 and 2019

		Average urban greenness			Type of urban greenness change					
					2001 to 2011			2001 to 2019		
	Population centres	2001	2011	2019	Decrease	Stable	Increase	Decrease	Stable	Increase
	number	percentage of area			percentage of population centres					
Total population centres	996	80.3	80.3	75.7	27.0	35.2	37.8	38.8	30.1	31.1
Size classes										
Large urban	31	75.8	75.4	69.6	29.0	16.1	54.8	77.4	0.0	22.6
Medium	58	82.0	81.6	77.7	46.6	12.1	41.4	70.7	8.6	20.7
Small	907	88.3	89.1	87.0	25.7	37.4	36.9	35.4	32.5	32.1
Regions										
Atlantic	101	94.3	95.6	93.9	6.9	55.4	37.6	20.8	50.5	28.7
Québec	268	86.0	87.2	82.8	13.1	51.1	35.8	30.6	43.7	25.7
Ontario	286	81.8	81.4	78.7	26.6	37.1	36.4	38.1	33.6	28.3
Prairies	234	61.5	62.6	55.5	41.9	9.8	48.3	43.6	8.1	48.3
British Columbia	107	84.0	80.6	72.9	49.5	27.1	23.4	67.3	15.9	16.8

Notes: Estimates of population centre greenness are based on the Normalized Difference Vegetation Index (NDVI) from MODIS. Water areas have been excluded. Includes population centres south of 60° latitude based on the 2016 population centre boundaries for all years to ensure consistency. Change in greenness compares the point in time to 2001 and does not represent a trend over time.

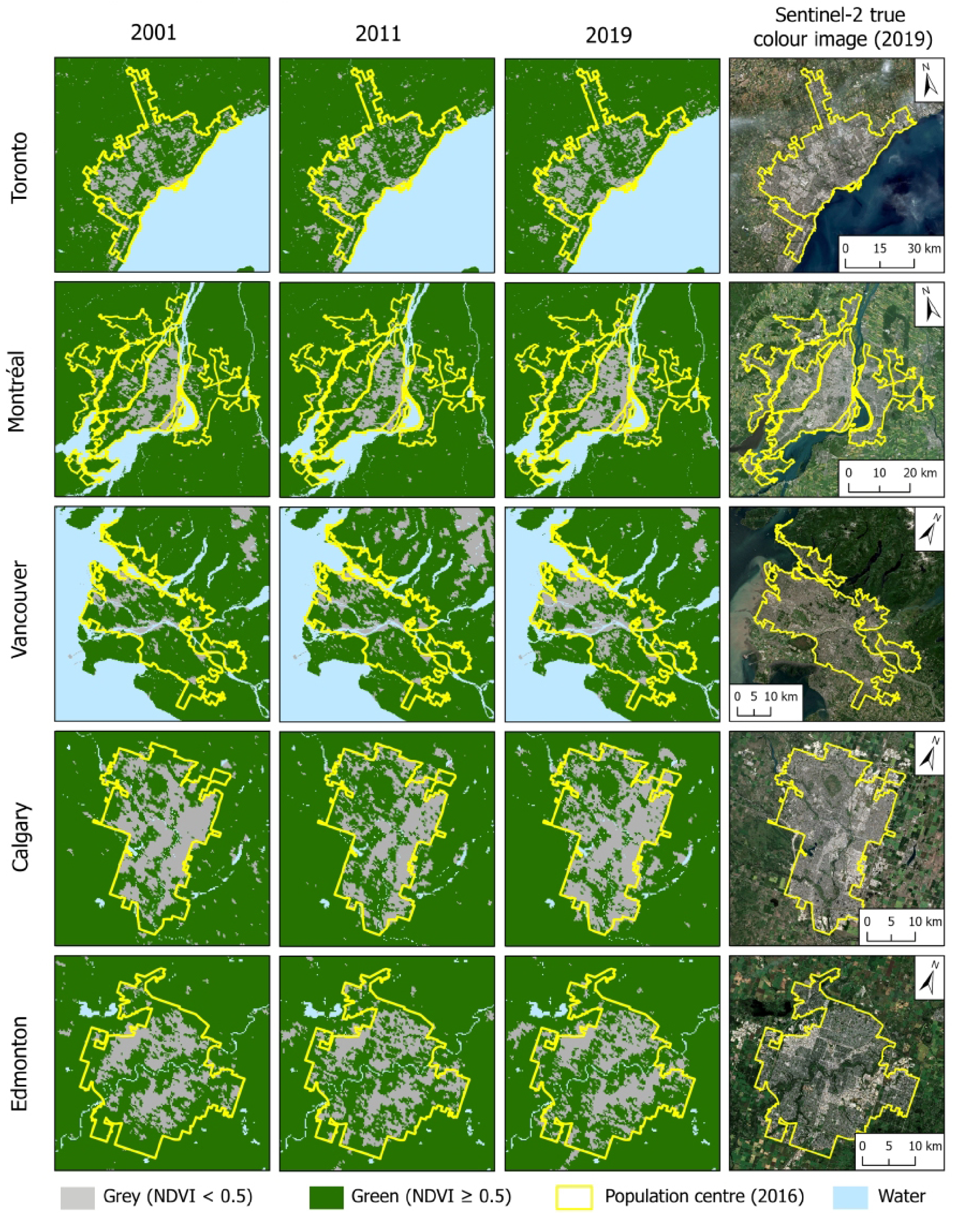
Source: Statistics Canada, Environment and Energy Statistics Division, special tabulation from Statistics Canada, 2020, *Corrected representation of the NDVI using historical MODIS satellite images (250 m resolution) from 2000 to 2019*, https://open.canada.ca/data/en/dataset/dc700f75-19d8-4913-9846-78615ca93784 (accessed April 29, 2020).

Chart 1
Urban greenness, by large urban population centre, 2001, 2011 and 2019



Notes: Estimates of population centre greenness are based on the Normalized Difference Vegetation Index (NDVI) from MODIS. Large urban population centres are presented here in order by size of land area, from largest to smallest.
Source: Statistics Canada, Environment and Energy Statistics Division, special tabulation from Statistics Canada, 2020, *Corrected representation of the NDVI using historical MODIS satellite images (250 m resolution) from 2000 to 2019*, https://open.canada.ca/data/en/dataset/dc700f75-19d8-4913-9846-78615ca93784 (accessed April 29, 2020).

Figure 2
Urban Greenness, top 5 large urban population centres



Sources: Statistics Canada, Environment and Energy Statistics Division, special tabulation from Statistics Canada, 2020, *Corrected representation of the NDVI using historical MODIS satellite images (250 m resolution) from 2000 to 2019*, https://open.canada.ca/data/en/dataset/dc700f75-19d8-4913-9846-78615ca93784 (accessed April 29, 2020); contains modified Copernicus Sentinel data 2019 processed by Sentinel Hub, https://www.sentinel-hub.com/explore/eobrowser/ (accessed January 15, 2021).

2001 drought impacted greenness measures

In general, the proportion of green area in population centres in 2019 was lower than in 2001. Approximately three-quarters of large (77%) and medium (71%) population centres had lower levels of greenness over this period (Table 1). In comparison, 35% of small population centres experienced a drop in greenness while 33% saw no change in greenness levels.

Between 2001 and 2011, the overall proportion of urban greenness remained the same. This finding can be largely explained by widespread drought conditions in 2001 across the Canadian south-west and an abnormally dry summer in Ontario and Quebec in the same year.[10] The 2001 drought had a significant impact on the condition of urban forests,[11] resulting in a lower proportion of green area in that year. In contrast, weather conditions during the growing season were more normal in 2011. [12]

An increase in greenness from 2001 to 2011 was observed for approximately half of large urban (55%) and medium (41%) population centres. A decrease was observed for 29% of large urban centres and 47% of medium population centres, which indicates that urbanization processes in these areas were likely significant enough to overcome the effect of weather conditions and contribute to the variation in the greenness measure. In 2011, urban greenness was stable or increased in the majority (74%) of small population centres relative to 2001.

Urbanization processes linked to population change a factor

Drought conditions monitoring indicates that the south of Canada experienced abnormally dry conditions to moderate drought in 2019.[13] While these conditions may have contributed to lower levels of greenness, they were less severe than those experienced in 2001, which suggests that in general the drop in urban greenness from 2001 to 2019 may be explained by urbanization processes.

Winnipeg, Milton, Kelowna, Windsor and Vancouver experienced some of the largest decreases in the share of green extent in 2019 compared to 2001 (Chart 2). These larger decreases in greenness are likely driven partly by the contributions of urbanization and the 2019 drought. For example, in Milton, the drop in greenness over the period coincided with a population increase of 350% from 2001 to 2016 (Figure 3 and Table 2). However, it is important to note that decreases in Winnipeg and Windsor may have been amplified by the effect of the emerald ash borer—an insect that has had a large impact on trees in some regions of the country.[14]

10. Wheaton, E., et al., 2008, "Dry times: hard lessons from the Canadian drought of 2001 and 2002," *The Canadian Geographer,* Vol. 52, no. 2, https://onlinelibrary.wiley.com/doi/full/10.1111/j.1541-0064.2008.00211.x (accessed September 18, 2020); Statistics Canada, 2002, "The western Canadian drought of 2001 – how dry was it?," *Vista on the Agri-Food Industry and the Farm Community*, Catalogue no. 21-004-XIE, http://publications.gc.ca/Collection/Statcan/21-004-X/21-004-XIE2002103.pdf (accessed September 18, 2018).
11. Hogg, E.H., J.P. Brandt and M. Michaelian, 2008, "Impacts of a regional drought on the productivity, dieback, and biomass of western Canadian aspen forests," *Canadian Journal of Forest Research,* Vol. 38, no. 6, https://doi.org/10.1139/X08-001 (accessed September 18, 2020).
12. Agriculture and Agri-Food Canada, 2020, *Canadian Drought Monitor*, https://agriculture.canada.ca/en/agriculture-and-environment/drought-watch-and-agroclimate/canadian-drought-monitor (accessed September 18, 2020).
13. Agriculture and Agri-Food Canada, 2020.
14. Natural Resources Canada, 2020, *Emerald Ash Borer*, https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/wildland-fires-insects-disturban/top-forest-insects-diseases-cana/emerald-ash-borer/13377 (accessed September 18, 2020); Epp, B., 2018, *Emerald Ash Borer Management in Manitoba,* Manitoba Sustainable Development, http://www.cif-ifc.org/wp-content/uploads/2018/10/ReducedFileSize-3-EAB-Manitoba-Brad-Epp.pdf (accessed September 21, 2020); City of Winnipeg, 2020, *Emerald Ash Borer (EAB)*, https://www.winnipeg.ca/PublicWorks/parksOpenSpace/UrbanForestry/EmeraldAsh.stm (accessed September 21, 2020).

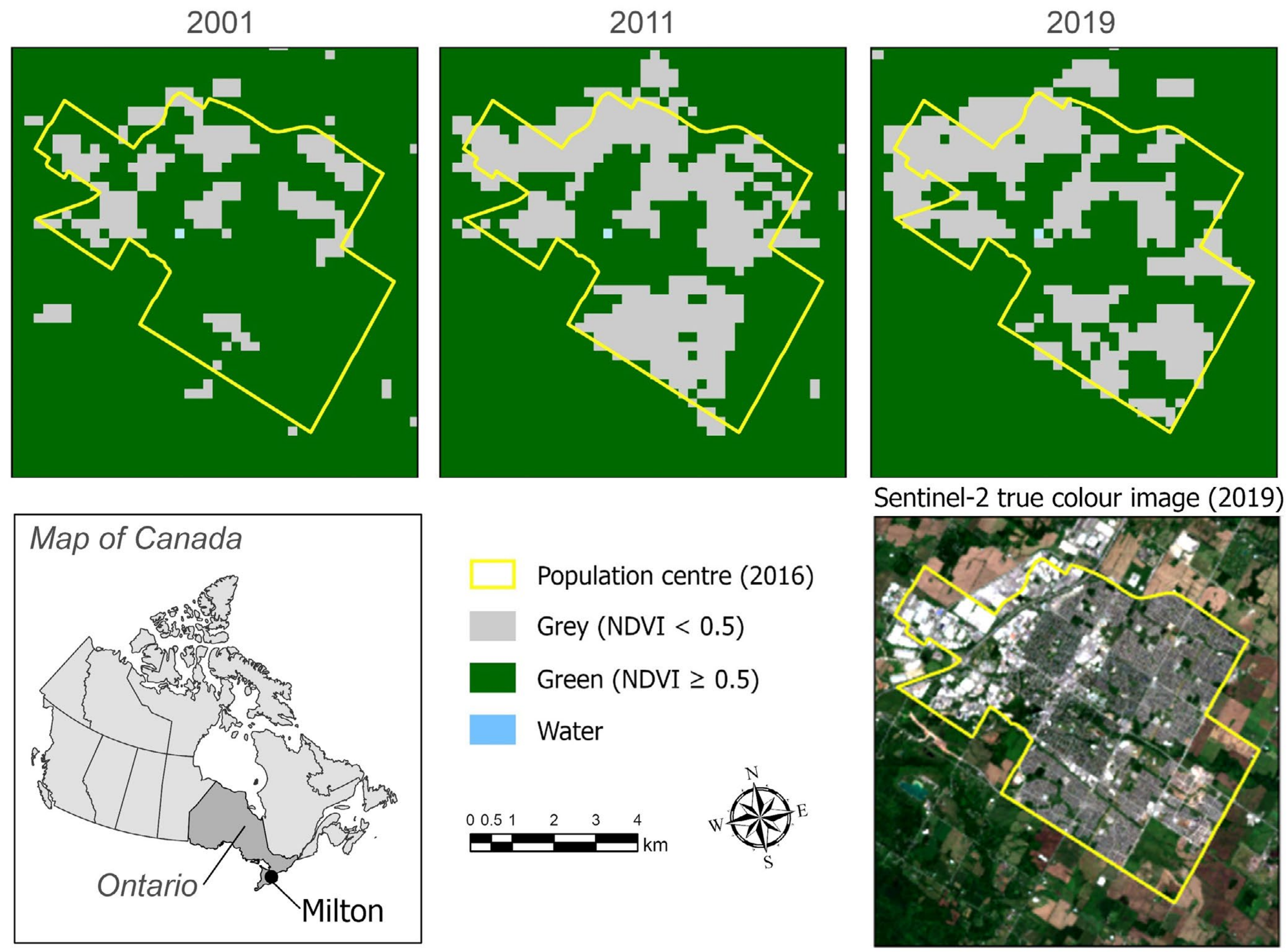
Table 2
Population count, by selected population centres, 2001, 2011 and 2016

	Population			Land area	Population change	
	2001	2011	2016		2001 to 2011	2011 to 2016
	number			km²	percentage	
Total population centres	23,399,918	26,917,492	28,508,127	16,733	15.0	5.9
Large urban population centres	17,110,433	19,728,652	20,938,295	9,487	15.3	6.1
Medium population centres	2,616,812	3,013,299	3,179,294	2,454	15.2	5.5
Small population centres	3,672,672	4,175,541	4,390,538	4,792	13.7	5.1
Large urban population centres with the largest decreases in the share of population centre greenness from 2001 to 2019						
Winnipeg	623,649	670,025	711,925	344	7.4	6.3
Milton	22,574	75,880	101,715	40	236.1	34.0
Kelowna	113,302	140,131	151,957	136	23.7	8.4
Windsor	265,926	277,970	287,069	176	4.5	3.3
Vancouver	1,807,734	2,124,443	2,264,823	876	17.5	6.6
Barrie	108,413	140,383	145,614	84	29.5	3.7
Abbotsford	100,250	115,011	121,279	69	14.7	5.4
Calgary	875,929	1,094,379	1,237,656	586	24.9	13.1
Ottawa-Gatineau (Ont.)	636,432	701,418	735,675	341	10.2	4.9
Edmonton	761,867	935,361	1,062,643	573	22.8	13.6

Notes: Includes population centres south of 60° latitude. Population data have been aggregated to the 2016 population centre boundaries for all years to ensure consistency. Water areas have been excluded.

Source: Statistics Canada, Environment and Energy Statistics Division, special tabulation based on the Census of Population.

Figure 3
Urban Greenness, Milton, Ontario



Sources: Statistics Canada, Environment and Energy Statistics Division, special tabulation from Statistics Canada, 2020, *Corrected representation of the NDVI using historical MODIS satellite images (250 m resolution) from 2000 to 2019*, https://open.canada.ca/data/en/dataset/dc700f75-19d8-4913-9846-78615ca93784 (accessed April 29, 2020); contains modified Copernicus Sentinel data 2019 processed by Sentinel Hub, https://www.sentinel-hub.com/explore/eobrowser/ (accessed January 15, 2021).