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High resolution stream water quality assessment in the Vancouver, British Columbia region: a citizen science study

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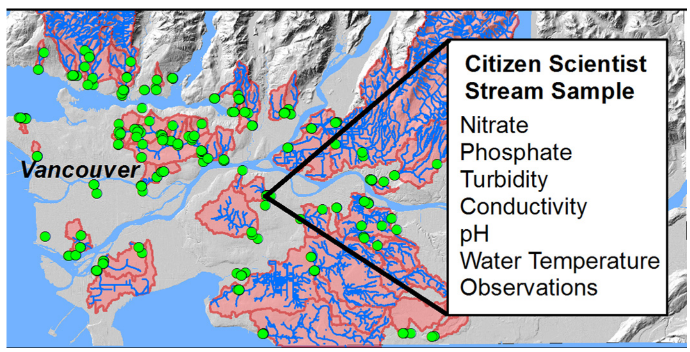
HIGHLIGHTS

- Volunteers collected data for seasonal and spatial water quality analysis.
- Agriculture and deciduous forest main drivers of nitrate and phosphate concentrations
- Disturbed land associated with increased phosphate concentrations
- Distinct spatial (catchment land cover type) and seasonal nutrient variations
- Conductivity more closely tied to land cover than turbidity.

GRAPHICAL ABSTRACT



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ABSTRACT

Changing land cover and climate regimes modify water quantity and quality in natural stream systems. In regions undergoing rapid change, it is difficult to effectively monitor and quantify these impacts at local to regional scales. In Vancouver, British Columbia, one of the most rapidly urbanizing areas in Canada, 750 measurements were taken from a total of 81 unique sampling sites representing 49 streams located in urban, forest, and agricultural-dominant watersheds at a frequency of up to 12 times per year between 2013 and 2016. Dissolved nitrate (NO_3-N) and phosphate (PO_4-P) concentrations, turbidity, water temperature, pH and conductivity were measured by citizen scientists in addition to observations of hydrology, vegetation, land use, and visible stream impacts. Land cover was mapped at a 15-m resolution using Landsat 8 OLI imagery and used to determine dominant land cover for each watershed in which a sample was recorded. Regional, seasonal, and catchment-type trends in measurements were determined using statistical analyses. The relationships of nutrients to land cover varied seasonally and on a catchment-type basis. Nitrate showed seasonal highs in winter and lows in summer, though phosphate had less seasonal variation. Overall, nitrate concentrations were positively associated to agriculture and deciduous forest and negatively associated with coniferous forest. In contrast, phosphate concentrations were positively associated with agricultural, deciduous forest, and disturbed land cover and negatively associated with urban land cover. Both urban and agricultural land cover were significantly associated with an increase in water conductivity. Increased forest land cover was associated with better water quality, including lower turbidity, conductivity, and water temperature. This study showed the importance of high resolution sampling in understanding seasonal and spatial dynamics of stream water quality, made possible with the large number of measurements taken with the help of trained volunteers. The results underscore the value of citizen science in freshwater research.

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1. Introduction

Land use change, including urbanization, deforestation and agricultural intensification, is combining with climate change to modify and often degrade freshwater systems across the globe (Allan, 2004; Sala et al., 2000; Dudgeon et al., 2006). In urbanizing areas of the world, the natural hydrological drainage system of creeks and streams is often replaced with networks of underground storm sewers which serve to drain cityscapes of accumulated precipitation, but are largely bereft of the flora and fauna and their various ecosystem services, including nutrient and sediment retention and microclimate regulation (Grizzetti et al., 2016). Meanwhile, to meet the needs of growing populations, agricultural intensification can cause nutrient eutrophication. This can lead to loss of biodiversity, increases in invasive species, shifts in the structure of food chains, and impairment of fisheries (Tilman, 1999). Cumulative urban and agricultural impacts on smaller streams and creeks in these scenarios can affect the larger receiving ecosystems, including lakes, rivers and ocean bodies. Since the process of urbanization and agricultural change in and around growing cities is often heterogeneous over time, changes and drivers of change in ecosystem conditions can be unpredictable, making effective freshwater monitoring a challenge.

In many communities in North America and around the globe, important monitoring data is increasingly being collected by volunteers who are trained in data collection. The use of these trained citizen scientist volunteers is cost effective and allows scientists to gather data on a larger geographic scale and over a longer time period than is possible in more traditional scientific research (Cohn, 2008). The use of citizen scientists is driven not only by the necessity of low cost data collection, but also by the motivation of volunteers themselves, who wish to contribute to scientific research and conservation efforts (Tulloch et al., 2013; Alender, 2016). Citizen science volunteers have collected data that have been successfully used on local to broad spatial scales, as well as over multiple years in a wide variety of research involving invasive species (Crall et al., 2010), migratory birds (Cooper et al., 2014), stream invertebrate data (Edwards, 2016), flood hydrology (Le Coz et al., 2016), and stream nutrients (Loiselle et al., 2016), among others. While concerns about data quality arise regarding citizen science (Bonney et al., 2014), with appropriate protocols, training, and oversight, volunteers can collect data of quality equal to those collected by experts (Danielsen et al., 2014).

The present study is designed to analyze data collected by citizen scientist volunteers from streams across greater Vancouver, British Columbia for the period 2013–2016 and compare results to an analysis of data that had been collected by the provincial government between 1971 and 2002 (Shupe, 2013), as well as to results of similar research in the Pacific Northwest. The particular focus for this study is the seasonality of water quality, in particular nutrients, and their relationship to agricultural, urban and forest land cover. Land cover in the area is variable and has been associated with a number of different pathways for nutrients or contaminants to flow into stream channels (Shupe, 2013). One of the key aspects of this study is also the use of citizen scientist in data collection. While proper training of motivated volunteers is essential, it is also important to be cautious when engaging volunteers in complicated, error prone, or time consuming measurements which may dampen their enthusiasm. Given these uncertainties in working in a new data collection program, a goal was to use a consistent, yet straightforward, data acquisition approach appropriate for uptake by volunteers. Successful outcomes of the use of volunteer data in this study contribute to the monitoring of change and impacts on Vancouver area streams and help further the use of citizen science in freshwater research.

2. Methods

2.1. Study site description

Metro Vancouver (Fig. 1) is made up of 21 municipalities, one treaty First Nation, and one unincorporated electoral area. Home to more than half of British Columbia's population, it is one of the fastest growing regions in Canada, increasing from approximately 1,000,000 people in 1966 to an estimated 2.4 million people in 2013 (Metro Vancouver, 2016; BCStats, 2016). Metro Vancouver is located at the terminus of the Fraser river and on a broad flood plain transitioning into mountains on the northern boundary of the municipality. A land cover dataset, derived from July 26, 2013 and February 3, 2014 15-m resolution Landsat 8 satellite imagery available from the US Geological Survey (USGS, 2014), indicates that the region is comprised of 42% forest, 15% urban, and 9% agriculture land with the remaining land being water, disturbed, grassland, and other land cover categories. Creation of the land cover dataset is described in Section 2.4.

2.2. Streams and sampling site selection

Initial stream selection was based upon Shupe (2013), who analyzed a historical water sampling data set dating from the 1970s that had been collected by the British Columbia Ministry of the Environment. Stream catchments ranged from predominantly forested (e.g. Mossom Creek watershed: 87% forest land cover, 11% urban land cover) to agriculturally dominant (e.g. Anderson Creek watershed: 53% agricultural land cover, 27% forest land cover, 20% urban land cover) to heavily urbanized (e.g. Still Creek watershed: 90% urban land cover). Sample sites were generally located in the mid to lower reaches of streams to monitor the sum of activities within each watershed and to facilitate watershed-level comparisons across the project area. The two large rivers in the region with watersheds extending to a significant extent outside the study area (i.e. the Fraser and Pitt Rivers) were excluded from the analysis. Additional streams and upstream sample sites were added to the investigation as the project progressed and additional volunteers joined the project.

2.3. Volunteer training, stream data collection and sampling site expansions

Between June 2013 and May 2016, field-based workshops were held 2–3 times a year to train volunteers in water sampling methods, with the goal of collecting stream data as part of the FreshWater Watch Program. A total of 192 citizen scientist leaders (CSLs) were trained. As part of their training, participants were required to pass an online training quiz. CSLs were provided with an online on demand training video for review of the appropriate methods. During training days, multiple sample measurements were made by teams of volunteers and compared to those taken by instructors. Any variabilities in the measurements were discussed and corrected during a post-field work sampling session. At the end of each training day, a testing kit was provided to each volunteer, containing written instruction sheets. CSLs were also assigned sampling locations in streams within their local or nearby community and instructed to sample in the immediate vicinity of the site, generally <25 m in both directions. CSLs were encouraged to collect data monthly or bi-monthly, though sampling frequency varied per site from 1 to 12 per year. Additional moderate sized streams (perennial) were incorporated into the project as the study progressed to facilitate the engagement of volunteers in sampling streams near or in the communities in which they lived. From June 2013 to the end of July 2016, volunteers assisted in the collection of 750 samples across a total of 81 unique sampling sites representing 49 streams. Fig. 1 shows the location of sample sites (data available without restrictions at freshwaterwatch.thewaterhub.org/content/data-map) and the watersheds in which they reside.

CSLs were trained to carefully draw water from accessible areas on stream banks using a bucket, or alternatively from bridges, if more accessible, by lowering a bucket into the water. CSLs were trained to rinse the buckets several times to ensure reside from previous sampling was not present. CSLs were also trained to avoid having buckets stir up sediment from the stream bottom.

Dissolved nutrients were measured in the field using colorimetric methods (Loiselle et al., 2016). Dissolved nitrate (NO_3-N) was measured

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