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Research article

Phosphorus flows in a peri-urban region with intensive food production: A case study

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ABSTRACT

Excess phosphorus (P) in peri-urban regions is an emerging issue, whereas there is global depletion of quality mined supplies of P. The flow of P across the landscape leading to regional surpluses and deficits is not well understood. We computed a regional P budget with internal P flows in a fairly discreet peri-urban region (Lower Fraser Valley, BC) with closely juxtaposed agricultural and non-agricultural urban ecosystems, in order to clarify the relationship between food production, food consumption and other activities involving use of P (e.g. keeping pets and horses and using soaps). We hypothesized changes that might notably improve P efficiency in peri-urban settings and wider regions. Livestock feed for the dairy and poultry sectors was the largest influx of P: the peri-urban land is too limited to grow feed grains and they are imported from outside the region. Fertilizer and import of food were the next largest influxes of P and a similar amount of P flows as food from the agricultural to urban ecosystems. Export of horticultural crops (berries and greenhouse crops) and poultry represented agricultural effluxes that partially offset the influxes. P efficiency was lower for horticultural production (21%) than animal production (32%), the latter benefited from importing feed crops, suggesting a regional advantage for animal products. There was 2.0, 3.8, 5.7 and 5.6 tonnes imported P per $ million farm cash receipts for horticulture, dairy, poultry meat and eggs. Eliminating fertilizer for corn and grass would reduce the ratio for the dairy industry. The net influx, dominated by fertilizer, animal feed and food was 8470 tonnes P per year or 3.2 kg P per person per year, and of this the addition to agricultural soils was 3650 tonnes P. The efflux in sewage effluent to the sea was 1150 tonnes P and exported sewage solids was 450 tonnes P. Municipal solid waste disposal was most difficult to quantify and was about 1800 tonnes P, 80% of which was partly reused in the urban regions and partly sequestered in landfill, which may be considered an efflux or a surplus. Reuse of rendering waste for feeding poultry significantly reduced P importation, but no rendering waste is used for cattle due to health concerns. Sensitivity analysis showed that variation in human population and the amount of P consumed per person in chicken and dairy products had the most influence on the total movement of P from agricultural to urban-ecosystems. There are current farm practices that mitigate P surpluses and new technologies are being developed to further reduce farm imbalances. However, current waste management policies that promote practices such composting of home wastes and exporting of poultry manure and biosolids to semiarid rangeland do little to enhance overall P cycling because the P is not returned to the farms producing feed and food for the peri-urban region. Sequestering in landfills may be a better solution until better ways are found to return surplus P.

1. Introduction

Phosphorus (P) fertilizer is currently used in 50–60% of global food production (Smil, 2000) and scarcity of P is thought to be a long term threat to food security (Cordell et al., 2009; Sheldrick et al., 2002). The removal of mineral nutrients from soils by crop

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production will eventually lead to depletion unless they are replaced with mined chemicals or recycled wastes. Managing nutrients requires understanding of cycling and balances at all levels: global, national, regional and local. For example, on an international a scale there are annual depletions of 4.5 kg P ha^{-1} from agricultural soils (Sheldrick et al., 2002). Paradoxically, some agricultural soils have become an unintended sink for P immobilization and storage, and in some regions are now a major source of P into water. In China for example about 35% of P inputs are lost to water (Liu and Chen, 2010) and P has become an important pollutant of surface waters. Regional surpluses of nutrients are often due to the flow of nutrients in organic forms (food, feed) from regions of low P concentrations such as crop-only farming regions to areas of high concentrations of animals and people. Even where there are efforts to recycle organic wastes, only a small proportion of crop land in many countries receives waste from livestock operations or cities due to costs and safety concerns. Commonly, crop lands near animal operations and waterways near cities receive excessive amounts. It was reported recently that of imported P into the city of Minneapolis-St Paul, MN, only 4% is exported as useful product, and conserving imported P would potentially sustain production for half of the food consumed (Baker, 2011). The increasingly unidirectional flow of nutrients away from crop farms is due to intensification of both livestock production and of human populations (cities), and in many cases the close proximity of the two. For example in Canada there are notable concentrations of livestock (and hence manure) near the three largest urban centres, Toronto, Montreal and Vancouver (Sheppard and Bittman, 2013).

Previous studies have examined P budgets at the level of barns (e.g., Gustafson et al., 2007), farms (e.g., Ghebremichael and Watzin, 2011), agricultural regions (e.g., Hajkowicz et al., 2005), watersheds (e.g., Meals et al., 2008), cities (e.g., Baker, 2011), and entire nations (e.g., MacDonald et al., 2012; Seyhan, 2009), but few studies have examined the relationship between locally grown food and urban populations in a peri-urban setting where there are also non-food related inputs like soaps and pet food (Khai et al., 2007). Very few nutrients are currently taken back from cities to the sources of the food or feed (Svirejeva-Hopkins and Reis. 2011) and leakage to the nearby environment is inevitable.

The Lower Fraser Valley (LFV) in British Columbia (BC) (Fig. 1) is a peri-urban region sharply delineated by steep mountains, the international border with the US, and by the Pacific Ocean, so that it comprises a discreet system for modelling P flows. The Pacific Maritime climate with a long growing season, mild winters and abundant rainfall makes possible intensive and diversified agricultural production; however, the region has limited agricultural land (about 55,000 ha or 0.02 ha per person). The region has a rapidly growing human population (currently >2.5 million, 9% increase between 2005 and 2011) residing mostly in Metro Vancouver and several smaller cities and towns, abutting and sometimes encroaching into the agricultural land. Commercial fishing in both marine and fresh waters is important as an economic activity, food source and environmental policy driver. The result of this confluence of factors is a dense human population closely integrated with intensive agricultural production farming, effectively an extended peri-urban setting, increasingly typical of many urban regions worldwide. Culturally, sourcing of local food has become a strong trend in many urban centres and there is the perception that co-locating production and consumption of food (so-called '100-mile' or 'locavore' diet) is a sustainable strategy (Peterson et al., 2015) and that a rise in urban agricultural activities such as backyard poultry rearing and urban farms contribute to sustainability.

The objective of this study was to quantify and analyze the P budget of an integrated peri-urban region, examining the inputs, outputs, surpluses and internal cycling of P within and between the agricultural ecosystem and urban ecosystems, where 'urban' is

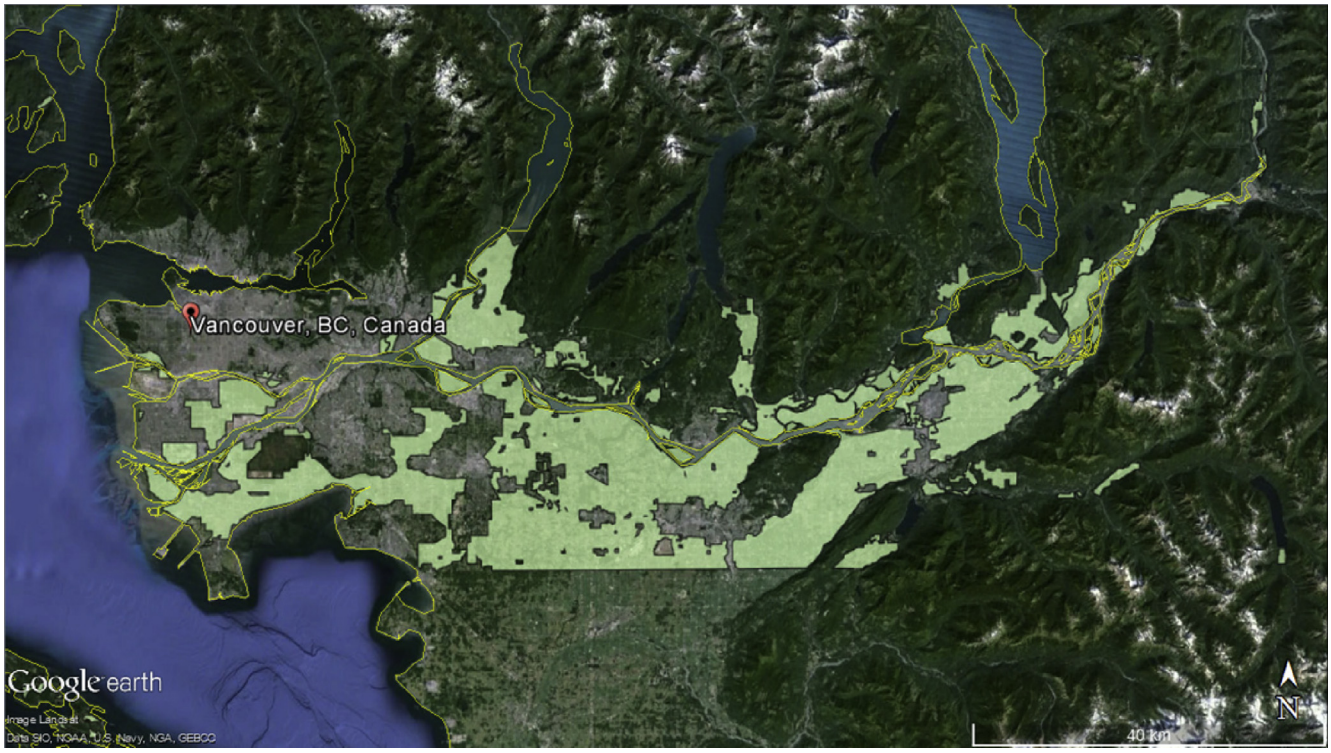

Fig. 1. Map of the peri-urban study region (Lower Fraser Valley, British Columbia) delineated by mountains, ocean and USA border. Urban areas are grey, agricultural areas are light green, mountains are dark green, and major waterways are demarked in yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)