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Critical levels and loads and the regulation of industrial emissions in northwest British Columbia, Canada

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HIGHLIGHTS

- LNG terminals proposed for NW British Columbia may double emissions of NO_x and SO_2.
- Soil critical loads of acidity averaged 181–219 meq m^{-2} yr^{-1}.
- Exceedance in small areas was predicted under worst-case emissions scenarios.
- Up to 20% of lakes were predicted to exceed critical loads of acidity.
- Critical levels and loads can inform LNG impact assessment and emissions regulation.

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ABSTRACT

Northwest British Columbia, Canada, a sparsely populated and largely pristine region, is targeted for rapid industrial growth owing to the modernization of an aluminum smelter and multiple proposed liquefied natural gas (LNG) facilities. Consequently, air quality in this region is expected to undergo considerable changes within the next decade. In concert, the increase in LNG capacity driven by gas production from shale resources across North America has prompted environmental concerns and highlighted the need for science-based management decisions regarding the permitting of air emissions. In this study, an effects-based approach widely-used to support transboundary emissions policy negotiations was used to assess industrial air emissions in the Kitimat and Prince Rupert airsheds under permitted and future potential industrial emissions. Critical levels for vegetation of SO_2 and NO_2 and critical loads of acidity and nutrient nitrogen for terrestrial and aquatic ecosystems were estimated for both regions and compared with modelled concentration and deposition estimates to identify the potential extent and magnitude of ecosystem impacts. The critical level for SO_2 was predicted to be exceeded in an area ranging from 81 to 251 km^2 in the Kitimat airshed owing to emissions from an existing smelter, compared with <1 km^2 in Prince Rupert under the lowest to highest emissions scenarios. In contrast, the NO_2 critical level was not exceeded in Kitimat, and ranged from 4.5 to 6 km^2 in Prince Rupert owing to proposed LNG related emissions. Predicted areal exceedance of the critical load of acidity for soil ranged from 1 to 28 km^2 in Kitimat and 4–10 km^2 in Prince Rupert, while the areal exceedance of empirical critical load for nutrient N was predicted to be greater in the Prince Rupert airshed (20–94 km^2) than in the Kitimat airshed (1–31 km^2). The number of lakes that exceeded the critical load of acidity did not vary greatly across emissions scenarios in the Kitimat (21–23 out of 80 sampled lakes) and Prince Rupert (0 out of 35 sampled lakes) airsheds. While critical loads have been widely used to underpin international emissions reductions of transboundary pollutants, it is clear that they can also play an important role in managing regional air emissions. In the current study, exceedance of critical levels and loads suggests that industrial emissions from the nascent LNG export sector may require careful regulation to avoid environmental impacts. Emissions management from LNG export facilities in other regions should consider critical levels and loads analyses to ensure industrial

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development is synergistic with ecosystem protection. While recognizing uncertainties in dispersion modelling, critical load estimates, and subsequent effects, the critical levels and loads approach is being used to inform regulatory decisions in British Columbia to prevent impacts that have been well documented in other regions.

1. Introduction

British Columbia seeks to join the global trade in liquefied natural gas (LNG); a total export capacity of approximately 236 Mt yr^{-1} has been proposed for the region (British Columbia Ministry of Natural Gas Development, 2015). Many of the proposed LNG export facilities plan to use gas-fuelled turbines to drive compressors that liquefy natural gas, and this, combined with increased shipping, may substantially elevate local nitrogen oxide (NO_x) and sulphur dioxide (SO_2) emissions. Furthermore, global LNG capacity is increasing, driven in part by gas production from shale resources, and there is growing concern that emissions from liquefaction facilities may lead to environmental impacts if not adequately managed. The potential for increased industrial air emissions from LNG production, particularly in regions with existing sources of NO_x and SO_2, suggests a need for science-based information to guide policy decisions, permitting, and airshed management at the regional level that is protective of the environment.

Sulphur dioxide and NO_x are recognized as having direct and indirect effects on vegetation, soils and surface waters (WHO , 2000; EEA, 2013; US EPA, 2011). Direct exposure to SO_2 at elevated concentration and for sufficient time has been shown to cause both visible injury to sensitive vegetation and growth and yield loss in agricultural crops and forest trees (Cape, 1993; Wulff et al., 1996; Likens et al., 1998; Horsely et al., 2000; US EPA, 2008). Elevated concentrations of NO_2 cause similar effects; however, concentrations reported to cause such injury are usually higher than for SO_2 (Mansfield et al., 1985; US EPA, 2008). Lichens, especially those with cyanobacteria symbionts, are among the most sensitive to these air pollutants, and are among the first species to be lost in regions with elevated industrial emissions (Richardson and Cameron, 2004).

Sulphur dioxide and NO_x are also precursors of ‘acid rain’ and can be deposited in wet deposition or fall as dry deposition leading to the acidification of soils and surface waters located in regions with shallow, base poor soils with low mineral weathering rates (Reuss and Johnson, 1986). Consequences of acidification include the loss of base cations from soils and an increase in aluminum (Al) concentration in soil water and surface waters, which can adversely impact forest ecosystems and lead to the loss of aquatic biota (Reuss and Johnson, 1986). In addition, nitrogen (N) is considered to be a limiting nutrient for many ecosystems and increased levels of N deposition can lead to eutrophication, which can impact community composition, cause the loss of sensitive species, alter forest productivity, and increase leaching of NO_3^- (nitrate) to surface waters (Aber et al., 1998). However, adverse effects caused by acidification or eutrophication are usually not immediate due to the inherent buffering capacity of soils and time-lags in ecosystem response (Cosby et al., 1985).

The concepts of both critical levels and critical loads have been adopted worldwide, perhaps most forcefully in Europe where these effects-based approaches have been key components in policy decisions that have led to dramatic decreases in SO_2 and, more recently, NO_x emissions (Rafaj et al., 2014; EEA, 2013). As defined by the Convention on Long-Range Transboundary Air Pollution (CLRTAP), critical levels are “*concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur according to present knowledge*”; whereas critical loads are “*a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to present knowledge*” (UNECE , 2004). Critical levels are predominately based on empirical data where impacts to sensitive biota (often lichens) have been observed, whereas critical loads are commonly based on steady-state models (for terrestrial and aquatic ecosystems) and are useful for determining the potential area or number of surface water bodies at risk from acidification during the longer term, but do not provide an estimate of when chemical or biological effects occur (UNECE , 2004). The critical load concept has also been embraced in Canada, both within the federal government where the objective is to reduce acidic deposition to meet critical loads (CCME, 2013), as well as regionally, such as in the Alberta Oil Sands, where the critical load concept has been incorporated into management decisions (Foster et al., 2001). Critical loads and exceedance have been previously determined for specific regions within British Columbia (Mongeon et al., 2010; Strang et al., 2010; Nasr et al., 2010; Krzyzanowski and Innes, 2010) and are now being used to inform provincial government decisions with respect to proposed industrial development (BC MOE, 2014b; 2014c, 2015b; ESSA et al., 2014b).

The objective of this study was to assess the risk of direct and indirect impacts of SO_2 and NO_x emissions on terrestrial and aquatic ecosystems in the Kitimat and Prince Rupert airsheds, British Columbia. We used air dispersion modelling with critical levels and critical loads to estimate the magnitude and areal extent of exceedances across a range of emissions scenarios. The assessment provided science-based estimates of potential impacts, which have been used to evaluate risk and inform the regulation of permitted air emissions. While the assessment focused on northwest British Columbia, the growth in LNG capacity worldwide may suggest a greater need for critical levels and loads assessments to support the management of regional air quality.

2. Methods

2.1. Study area

Kitimat (54° 0′ N, 128° 41’ W) is at the northern end of a 90 km long fjord with a 12 km wide valley confined by 1500–1800 m high mountains to the east and west (Fig. 1). The climate in Kitimat is temperate: the July mean high is 22 °C and the January mean low is −4 °C, while the annual precipitation is 2211 mm (Environment Canada, 2015). The Kitimat Valley is mainly forested with western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), Pacific silver fir (*Abies amabilis*), lodgepole pine (*Pinus contorta* var. *latifolia*), and western redcedar (*Thuja plicata*). The valley bottom is dominated by stands of 30–50 year old regenerating western helmlock. This is bisected by the Kitimat River and floodplains which support stands of deciduous black cottonwood (*Populus*