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Technical Reports

Assessing Forest Health in the Athabasca Oil Sands Region

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Final Report



The average $\text{NH}_4\text{-N}:\text{NO}_3\text{-N}$ ratios for annual bulk deposition and throughfall, considering all years and sampling locations were 1.8 and 2.0, respectively, indicating that over the monitoring network deposition of $\text{NH}_4\text{-N}$ was approximately double that of $\text{NO}_3\text{-N}$ (Fig. 3.2). The highest $\text{NH}_4\text{-N}:\text{NO}_3\text{-N}$ ratios in bulk deposition during summer were found at the Peat Pond and W1 sites located 6 and 8 km. from the industrial center; winter ratios at these sites were also among the highest. However ratios in bulk deposition in winter only occasionally exceeded 2.0.

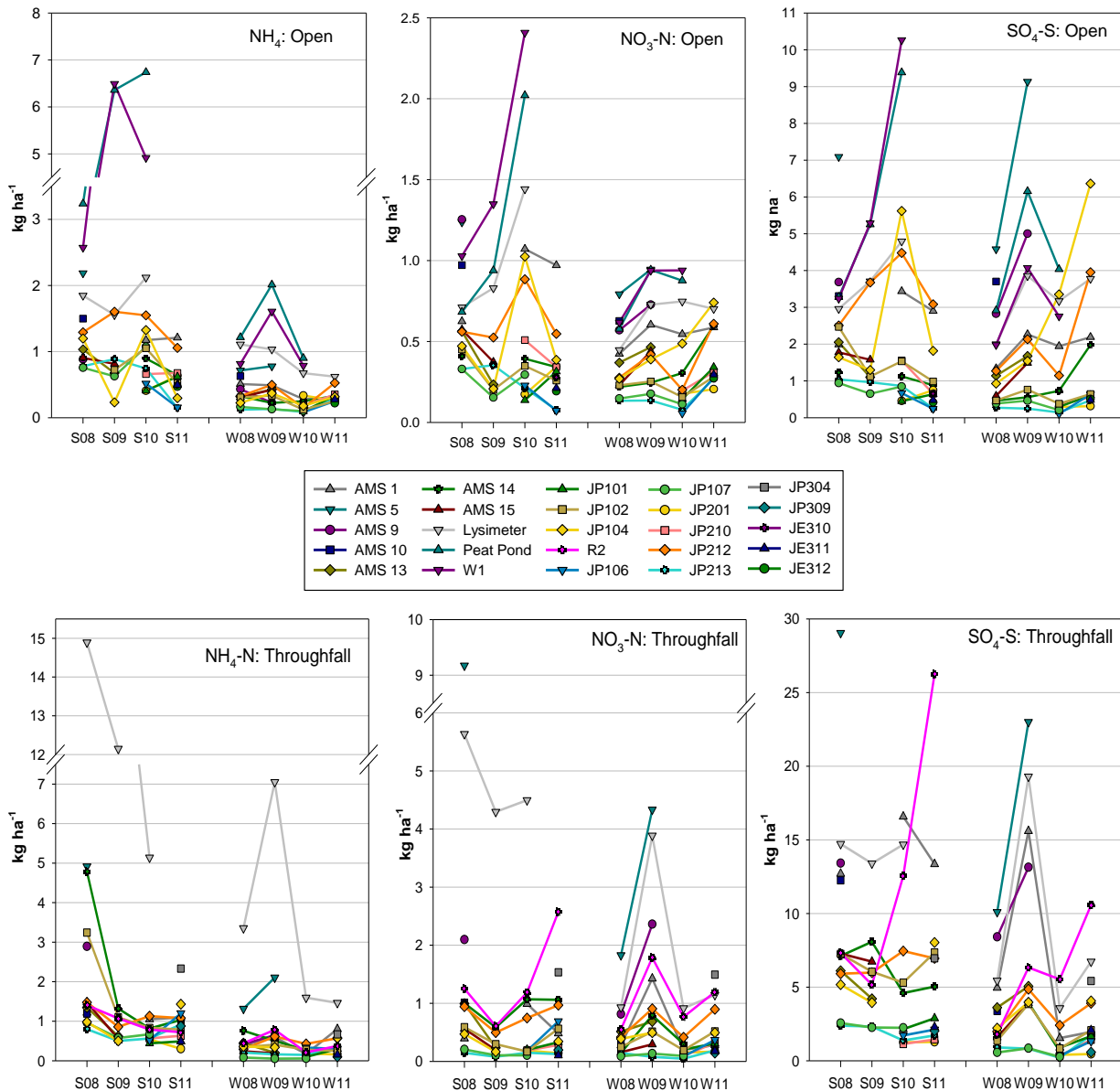


Figure 3. 2 Temporal patterns of summer and winter deposition of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{SO}_4\text{-S}$ in (a) forest clearings (open) and (b) throughfall under jack pine in the Athabasca Oil Sands Region.

The IER deposition maps illustrate the rapid drop-off of $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and their sum (DIN; Figs. 3.3) with distance from the industrial center, which is near the Lysimeter site shown on the maps. Sulfate deposition shows a larger footprint (Fig. 3.4), although sites with $>12 \text{ kg S ha}^{-1} \text{ yr}^{-1}$ are generally restricted to a zone within approximately 30 km of the Lysimeter site. Of particular interest is a comparison of the deposition maps showing the combined deposition of DIN and $\text{SO}_4\text{-S}$ and base cation deposition (Fig. 3.4). It can readily be seen that estimated base cation deposition is greater than the sum of $\text{DIN} + \text{SO}_4\text{-S}$ deposition throughout the study region. However, it should be emphasized that this data set may be substandard as the base cation deposition values in throughfall are for only one year (Oct 2009 to October 2010) and base cation data were not collected at as many sites as for N and S. Estimated values, based on distance/deposition relationships (see Fig. 3.1) were used to provide missing data base cation throughfall deposition for some combinations of monitoring sites and seasons (summer or winter).

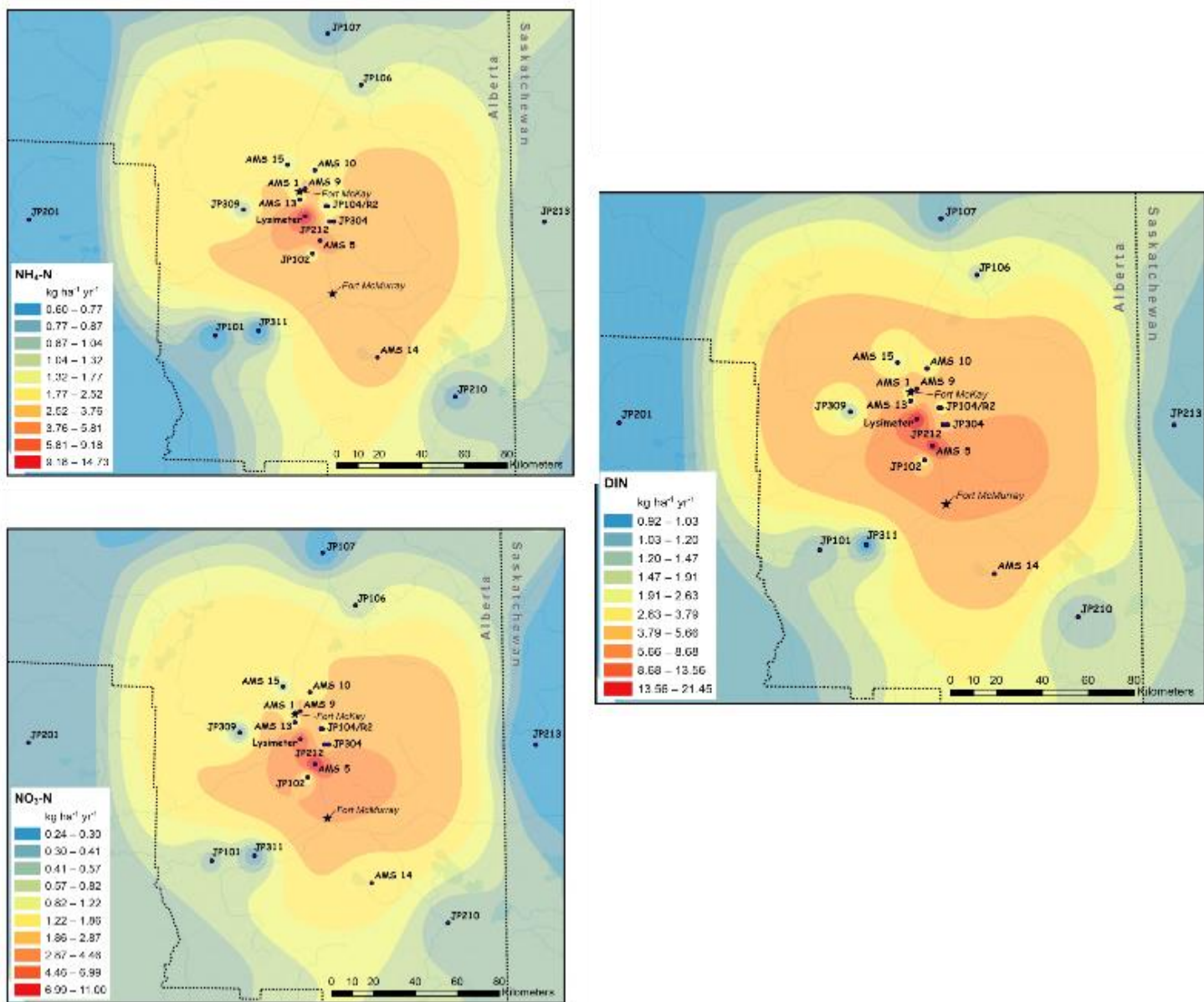


Figure 3. 3 Dissolved inorganic nitrogen (DIN; sum of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$), $\text{NH}_4\text{-N}$, and $\text{NO}_3\text{-N}$ deposition ($\text{kg ha}^{-1} \text{ yr}^{-1}$) in the AOSR. Maps were developed from ion exchange resin (IER) data collected from October 2008 to October 2012 from 21 monitoring sites using inverse distance weighting.

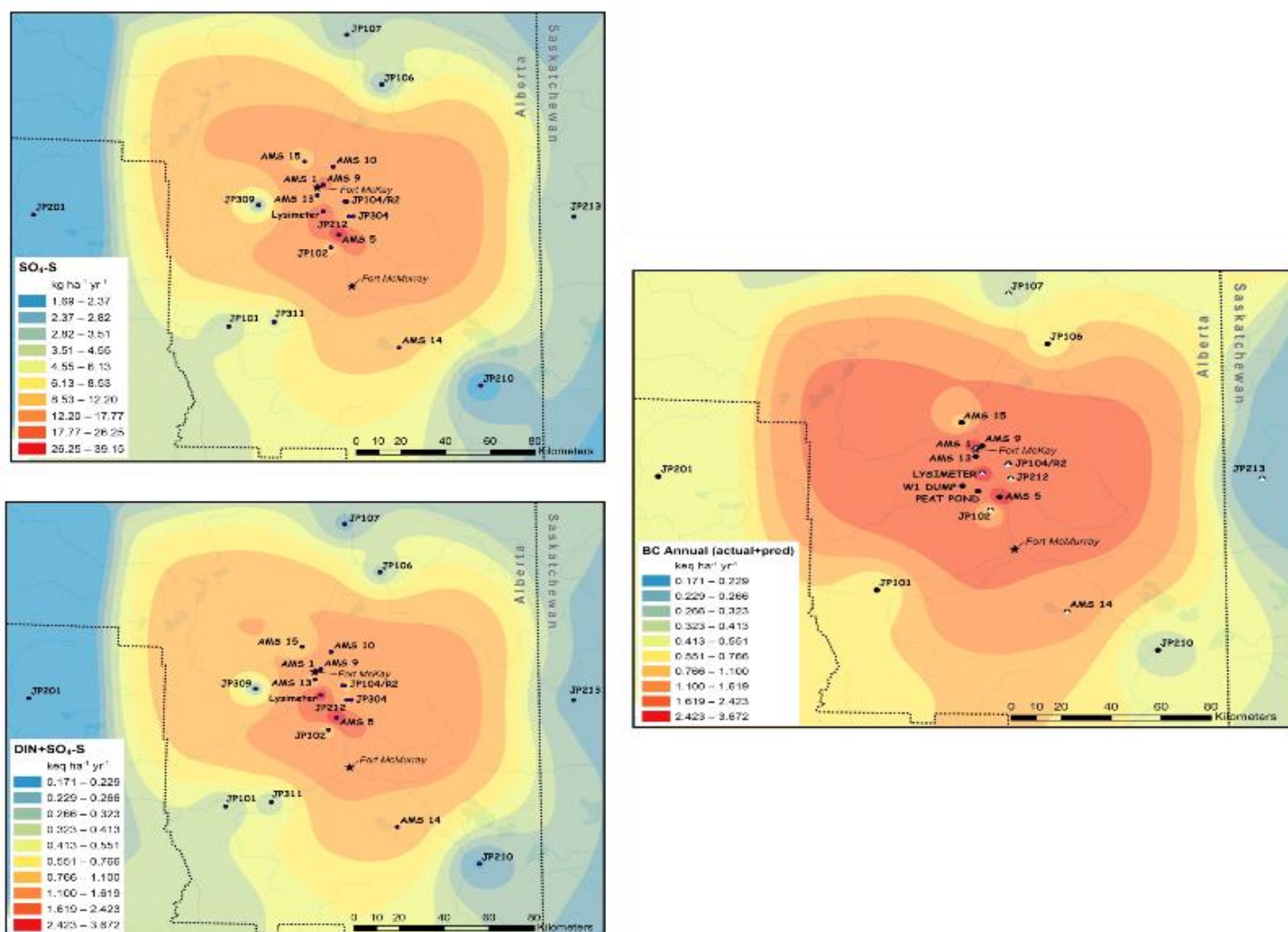


Figure 3. 4 Maps of $\text{SO}_4\text{-S}$ deposition in $\text{kg ha}^{-1} \text{yr}^{-1}$ and $\text{DIN} + \text{SO}_4\text{-S}$ and sum of base cations in $\text{keq ha}^{-1} \text{yr}^{-1}$ in the AOSR.

3.4 Discussion

Deposition in throughfall of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ were reduced by 80 and 91% at 20 km from the industrial center demonstrating the rapid drop-off with distance from the source area. In contrast throughfall deposition of base cations and $\text{SO}_4\text{-S}$ only decreased by 72 and 56% at 20 km and by 75% at 25 and 53 km, illustrating the larger footprint of $\text{SO}_4\text{-S}$, and to a lesser degree, of base cation deposition in the AOSR.

Historical emphasis on N monitoring, modeling and effects in the AOSR has focused almost exclusively on oxidized forms of N as evidenced by N and S deposition modeling work that includes only NO_x and SO_x (Davies, 2012). However, our deposition data clearly show that atmospheric inputs of N in reduced forms are greater than oxidized forms. Atmospheric concentrations of gaseous NO_y and NH_3 in the AOSR are enhanced; however, much of the

reduced N input in the region is likely in particulate form as evidenced by stack emissions (Wang *et al.*, 2012; Watson *et al.*, 2011) and the steeply declining patterns of deposition with distance from the source zone.

Although deposition of NH₄-N is on average double that of NO₃-N deposition in the AOSR, emissions inventories of the National Pollutant Release Inventory (NPRI, 2010, 2011) report that NH₃ emissions from stationary sources were only 3% as large as NO₂ emissions in 2010 and 2011. Furthermore, the NPRI inventory does not include NO_x emissions from mobile sources, which in 2008 made up 40% of the anthropogenic NO_x emissions in the AOSR (Davies, 2012). The discrepancy between the reported dominance of NO_x emissions and deposition data showing that NH₄-N deposition is double that of NO₃-N deposition is apparently due to unreported elevated emissions of particulate NH₄ and likely also because of underestimates in reported NH₃ emissions. Emissions of particulate matter mass is reported in the emissions inventory (NPRI, 2010, 2011), but chemical characterization of particulate matter emissions is not.

In summary, publicly available N emissions data for the AOSR are inadequate to address quantitatively what sources and processes are responsible for the observed atmospheric deposition in throughfall and bulk deposition. However, it is clear that emissions and atmospheric deposition of reduced forms of N (NH₃ and NH₄⁺) are much greater than previous understanding and available emissions inventories indicate.

3.4.1 Potential Ecological Effects of Air Pollution in the AOSR

Concentrations of N in foliage of *P. banksiana* (jack pine) and in the lichen species *Evernia mesomorpha* and *Hypogymnia physodes* were positively correlated with atmospheric concentrations of NO₂ (Laxton *et al.*, 2010), indicating that N deposition in the AOSR enriches the N status of vegetation and lichens (Davies, 2012) in the more polluted portions of the AOSR. Likewise, a 2004 survey of the TEEM plots revealed that S concentrations in foliage of jack pine (total S and inorganic S) and of the forest floor, and both N and S levels in lichen tissue, increased with increasing atmospheric deposition (C.E. Jones & Associates Ltd., 2007). Further work is needed to evaluate possible biological responses to this N and S enrichment and its spatial extent. These findings suggest that the areas of highest potential risk of N and S deposition effects are limited to within 20-30 km of the main industrial zone of the AOSR—and possibly even a smaller zone for N effects.

Although soils in jack pine stands are naturally acidic with low base cation saturation, the consensus of previous studies in the AOSR is that there is limited potential for acidification of soils or lakes under current conditions (Hazewinkel *et al.*, 2008; Jung *et al.*, 2013; Whitfield *et al.*, 2009; Watmough, this report). A field study at four forest sites in the AOSR found that soil pH increased from 2005 to 2010. The authors proposed that likely mechanisms for the soil pH increase were decreased H⁺ input as a result of decreasing S deposition and increased base cation deposition (Jung *et al.*, 2013). The results of our study also indicate that base cation deposition closely tracks acidic deposition in the form of N and S deposition. Watmough *et al.* (2014)

concluded that despite extremely low soil base cation weathering rates in the region, the risk of soil acidification is mitigated to a large extent by high base cation deposition as shown in Fig. 4.1.

3.5 Conclusions

As noted previously for other pollutants, throughfall deposition of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ decreased exponentially within a 20-25 km zone surrounding the industrial center (Fenn *et al.*, 2015). At a distance of 20 km from the industrial center N deposition decreased by 88%, while S and base cations decreased by 56 and 72% respectively, showing a greater footprint. Deposition of $\text{NH}_4\text{-N}$ in the AOSR was on average double that of $\text{NO}_3\text{-N}$. Higher deposition of reduced forms of N compared to oxidized forms had not previously been well documented except for data showing elevated atmospheric concentrations of NH_3 in the AOSR (Bytnerowicz *et al.*, 2010a,b). More studies are needed to better understand the emissions sources and chemical forms of reduced N that contribute to $\text{NH}_4\text{-N}$ deposition in the region.

Results of this study support the hypothesis that eutrophication effects to sensitive organisms such as epiphytic lichens may be of greater concern than acidification because acidic deposition is matched by equivalent amounts of buffering base cation deposition (Watmough *et al.*, 2014). However, the zone at risk of excess N effects is limited in size as indicated by the steep decrease in N deposition with distance from the source areas.

3.6 References

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