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Oligotrophication of boreal headwater rivers: persistent and widespread decline of inorganic nitrogen and phosphorus.

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Export of nutrients from watersheds is largely regulated by the capacity of terrestrial and aquatic ecosystems to use resources in the face of processes that promote hydrologic export and release to the atmosphere. For nitrogen (N) and phosphorus (P) soil and plant uptake systems can be particularly strong sinks, taking up useable forms of N and P. Despite this efficient use, over long time scales ecosystems may be subject to substantial N and P losses that varies across time and space. Understanding the trends and seasonality of these nutrient losses on different ecosystems becomes important for the long-term maintenance of terrestrial nutrient limitation as well as for patterns of resource export to recipient aquatic ecosystems. To improve the understanding of nutrient losses from different land covers in natural boreal catchments we used long-term data (2008-2020) from the interdisciplinary, multi-scale Krycklan Catchment Study (KCS) in northern Sweden. We focused on 13 intensively monitored catchments with areas ranging from 12 ha to over 6780 ha and with different percentage of land cover characteristics; primarily forest (almost 100%), wetlands (nearly 50%) and lakes. For both P and N the main focus was on the dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN). We evaluated the trends in stream nutrient concentration using Mann-Kendall tests to determine the Theil-Sen estimate slopes and a Seasonal Mann Kendall to evaluate the seasonality of the trends. Our results show a steady decline of DIP in all catchments and a decline in most catchments for DIN (11 out of 13). Although all catchments have a negative DIP trend we could not relate the magnitude of the slope to specific land cover or catchment size. Contrary to what we expected, negative trends of DIN during summer were inversely related to forest coverage, meaning that catchments with higher coverage of forest displayed a slower DIN decrease. While negative trends were evident at annual scales for both inorganic nutrients, more detailed assessment revealed time windows when most of this long-term change occurred. Here, seasonal Mann Kendall tests revealed almost opposite seasonality for both inorganic nutrients, with significant DIP decline during the autumn, winter and spring and strong DIN declines during summer. We suspect these seasonal differences are linked to different processes that are being affected differently by changing seasonal characteristics, including warmer and shorter snow cover periods during winters and warmer and longer summers, respectively. Finally, in light of ongoing increasing trends of dissolved organic carbon (DOC), DIP:DOC and DIN:DOC molar ratios are also steadily increasing over time in most catchments. As a result nutrient balances in the river waters are becoming even more carbon rich and N-P poor, offsetting the balance mainly in growing season for DOC:DIN ratio and in spring and

autumn for DOC:DIP ratio.