Have global concentrations of dissolved silicon concentrations and yields changed over time?

Long-term changes in concentration and yield of riverine dissolved silicon from the poles to the tropics

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What influences riverine silicon cycling and are there changes over time related to climate? Silicon availability in marine ecosystems supports diatom growth, which impacts the carbon cycle in marine and freshwater environments globally. Marine concentrations of silicon are mainly driven by terrestrial weathering and riverine transport. The amount of silicon exported by rivers is influenced by freshwater biotic uptake, vegetative uptake, and sedimentation. The authors investigated how changes in riverine silicon were related to land use or climate perturbations in 60 riverine ecosystems from the tropics to the polar regions.

Which biomes had the highest and lowest riverine silicon concentrations and yields? AT which types of sites did yield increase?

- Silicon concentrations were highest in tropical rainforest streams and a coniferous forest stream. Concentrations were lowest in polar desert and Arctic tundra streams. Yield was highest in tropical savanna, tropical rainforest, and Antarctic polar desert streams. Yield was lowest in an Arctic tundra stream.
- Mean discharge of silicon into the marine environment increased significantly over time at 8 sites and marginally significantly at 8 additional sites. Sites with increased discharge were temperate deciduous forest, polar desert, tropical rainforest, Arctic-boreal transition, and tropical savanna.

Did silicon concentrations and yields increase or decrease over time? Were trends the same within a biome? What factors might be driving these trends?

- Over time silicon concentration increased at 25 sites, and decreased at 23 sites and did not change at 12 sites. The only biome in which all sites had the same trend was the alpine tundra. Most trends observed were likely a combination of climate shifts and local watershed factors.
- Most sites had changes in silicon yield over time, with increases at 37 sites and decreases at 12 sites. Several sites had divergent concentration and yield over time, giving some insight into the discharge-concentration relationship with higher flows generally associated with lower concentrations.
- Most sites had increasing silicon yields over time across biomes and land use histories. However, large rivers draining into the Arctic Ocean had decreasing silicon yields over time. These decreases may be driven by increased vegetative uptake, increased biotic uptake from higher aquatic primary productivity, and sediment retention.

Which factors were most highly associated with changes in silicon concentration and yield?

- The model that best described long-term change in silicon concentration and yield was land use and land cover. The most influential variables were percent shrubgrass, which had a positive effect, and percent open water, which had a negative effect. Percent forest cover had a smaller negative impact.
- Long-term trends in silicon concentration and yield were more strongly associated with land use and land cover than with lithology, climate, drainage area, or availability of nitrogen or phosphorus.

Were changes in silicon concentration and yield driven by changes in biogeochemistry or flow regime?

- Silicon concentrations over time were more sensitive to watershed biogeochemistry changes than to changes in flow regime. However, long-term changes in silicon yield were driven by changes in biogeochemistry at 21 sites and by changes in flow regime at 23 sites.

Which systems showed the strongest influence of biogeochemical changes? Is additional work needed?

- The systems with the strongest impact of biogeochemical change were Arctic tundra, alpine tundra, and Arctic-boreal transition sites. The effects of climate change at these sites is rapid and dramatic, and greater understanding of how these changes impact silicon concentration and yield is needed.

Was there seasonality in the changes in silicon concentration and yield?

- Long-term changes in silicon concentration and yield had strong seasonal signals. The directions and magnitudes of seasonal patterns differed among biomes. This highlights the importance of considering temporal shifts in the timing of peak concentration and yield to help understand mechanisms of change.

Research Approach/Methods

- The authors analyzed long term data sets from 60 streams and rivers that represent nine distinct biomes: Arctic tundra, alpine tundra, polar desert, Arctic-boreal transition, temperate coniferous forest, temperate deciduous forest, temperate grassland, tropical rainforest, and tropical seasonal forest/savanna.
- Their data sets had 15 to 54 years of silicon concentration data with observations distributed across seasons and at least 15 years of continuous daily discharge data. In order to include data from the Arctic biome, they used an Arctic stream with a shorter data set.
- The authors used the weighted regression on time, discharge, and season model to estimate daily silicon concentrations and fluxes and flow-normalized concentration and flow-normalized flux. They calculated area-normalized silicon fluxes and flow-normalized silicon yields. They used flow-normalized data to remove the impact of flow level when assessing trends over time.
- The researchers evaluated absolute and percent change in flow-normalized concentrations and yield using EGRETci and evaluated their likelihood with block bootstrapping with a 70%

likelihood cutoff for significance. They used a Mann-Kendall non-parametric trend test to evaluate trends in mean annual discharge.

- The authors evaluated whether silicon concentration was influenced by site-specific factors, changes in streamflow regime or biogeochemical processing. They then determined whether concentration and yield trends were more influenced by the streamflow regime or biogeochemical processing, or by a mixture of both.
- They determined whether seasonal variation in silicon concentration and yield aligned with seasonal patterns in temperature and precipitation across biomes using a seasonality index they calculated from monthly mean temperature and precipitation data.

Keywords dissolved silicon, riverine silicon flux, silicon cycling, river silicon biogeochemistry, biome-specific river silicon exports

Images

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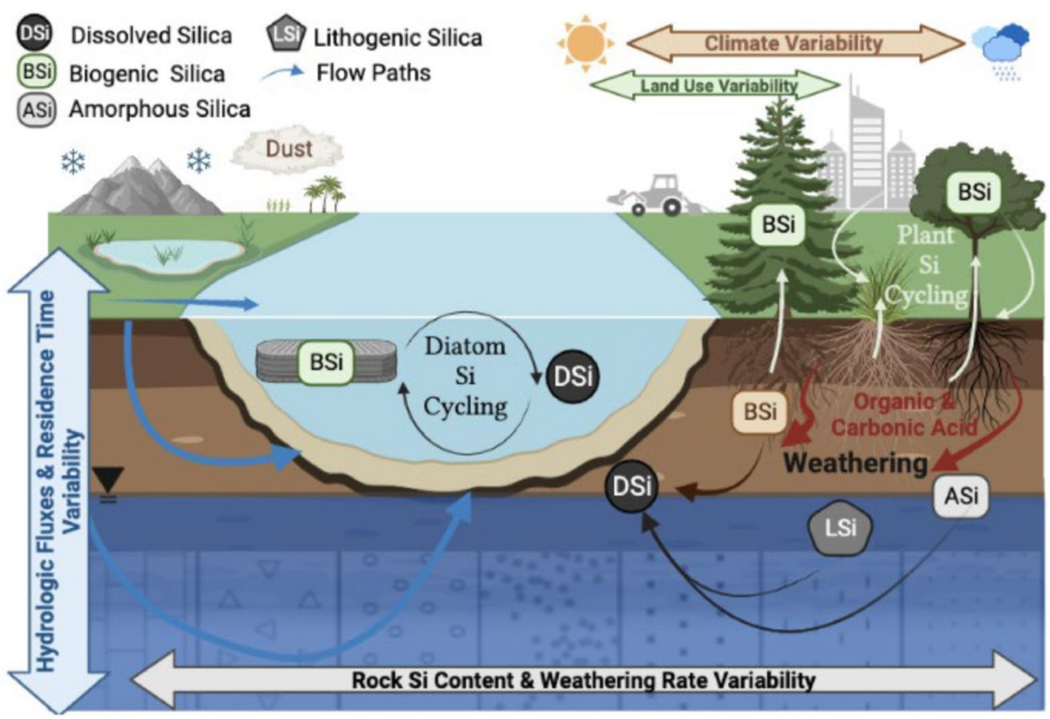

Figure 1 Jankowski et al. 2023. Conceptual figure of the terrestrial and aquatic controls on riverine dissolved silicon (DSi) concentrations and yields. Silica derived from geogenic processes occurs either through the breakdown of rock or soil at a specific site or through the input and eventual breakdown of dust. DSi can be taken up through biotic processes (e.g., vegetation or diatoms) or precipitated as amorphous silica. DSi is transported from land to streams across various hydrologic flow paths. The interaction of the processes and their control on DSi concentrations and fluxes is dependent on the type of underlying lithology, land cover, land use, and climate. Double headed arrows in the figure indicate a wide range of variability of a given process.

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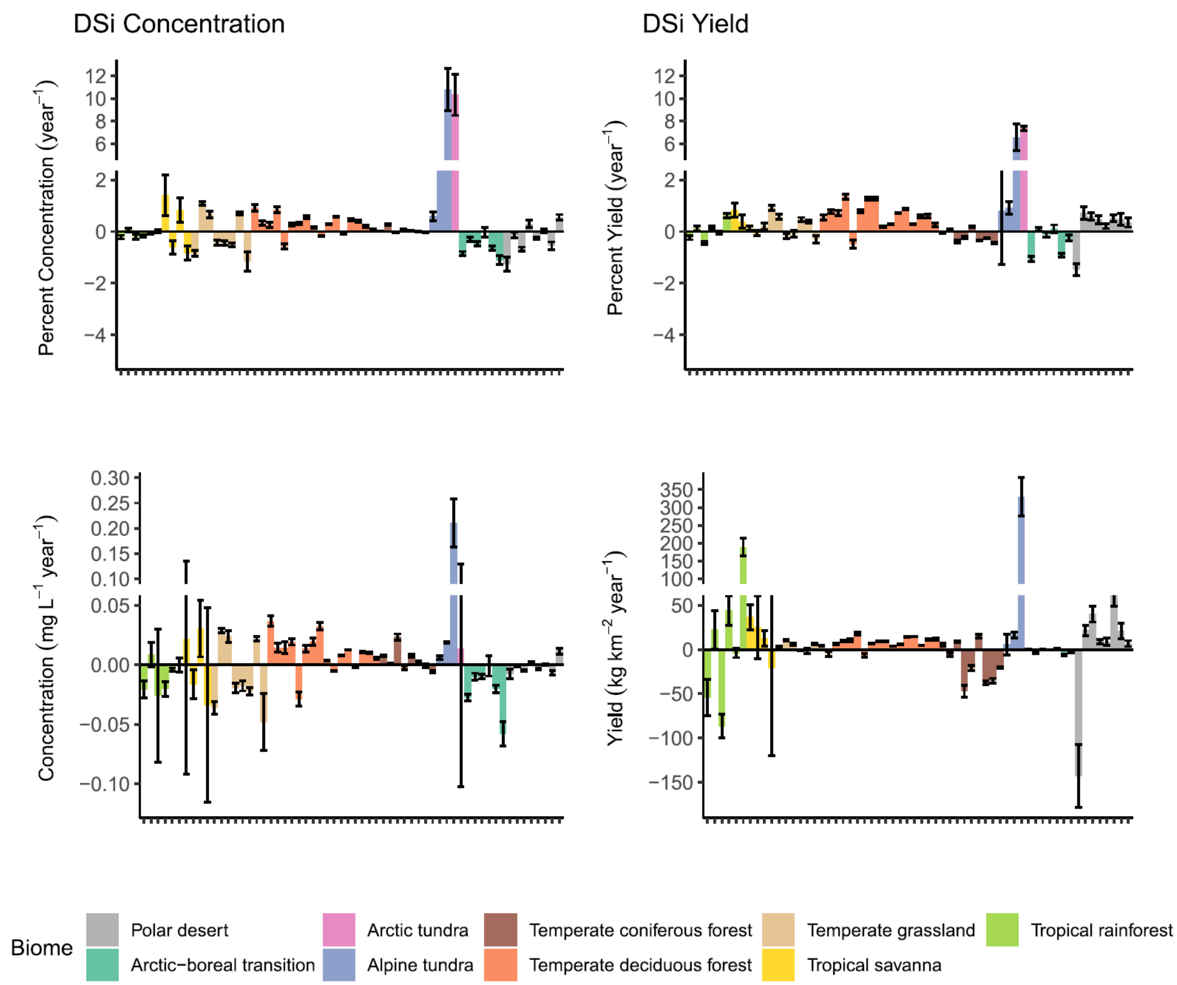

Figure 5 in Jankowski et al. 2023. Changes in dissolved silicon (DSi) concentration and yield shown as (a) percent change in concentration per year, (b) percent change in yield per year, (c) absolute concentration change per year, and (d) absolute change per year. Bars are individual sites and are colored by biome. Error bars are 95% confidence intervals of bootstrapped trend estimates.

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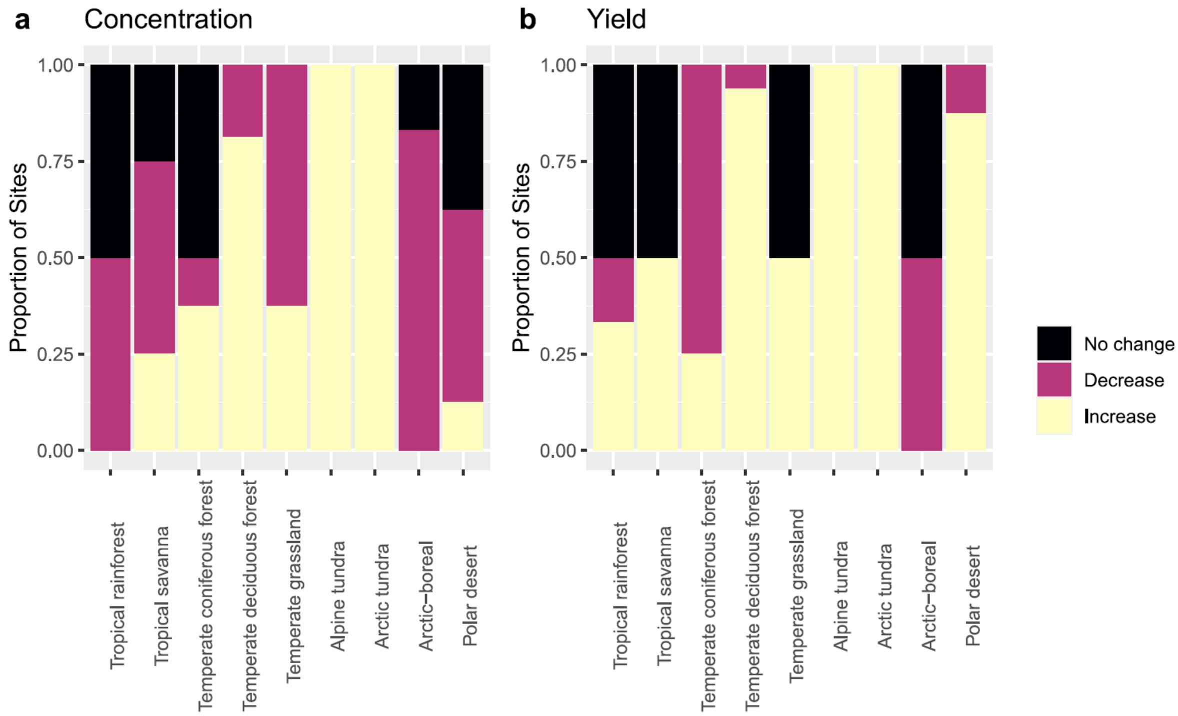

Figure 6 in Jankowski et al. 2023. Proportion of sites with increasing, decreasing, and no change in dissolved silicon (DSi) (a) concentration and (b) yield by biome.

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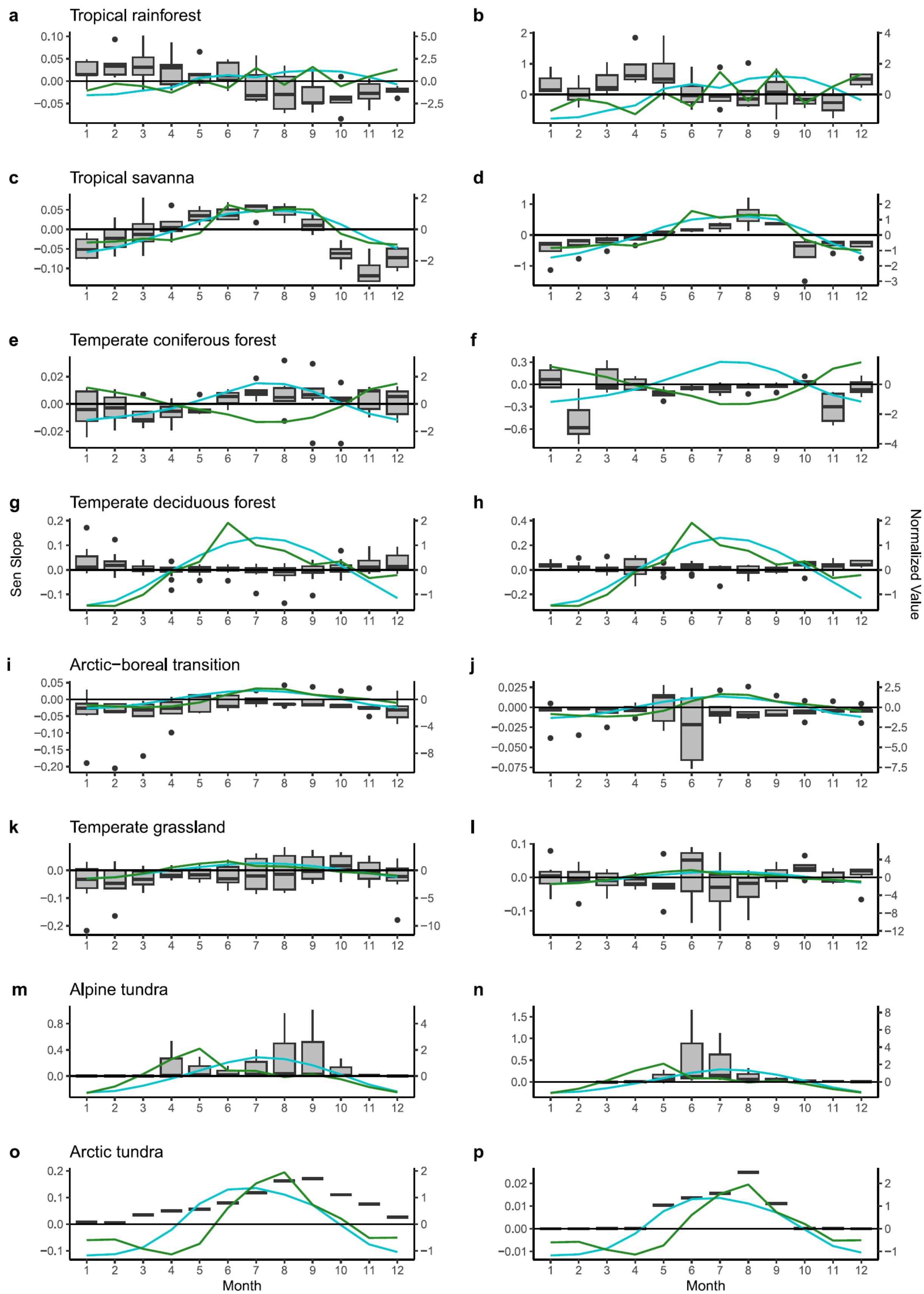

a
Tropical rainforest
b
c
Tropical savanna
d
e
Temperate coniferous forest
f
g
Temperate deciduous forest
h
i
Arctic−boreal transition
j
k
Temperate grassland
l
m
Alpine tundra
n
o
Arctic tundra
p
Sen Slope
Normalized Value
Month
Month

Figure 8 in Jankowski et al. 2023. Monthly trends in dissolved silicon (DSi) concentration (panels a, c, e, g, i, k, m, and o) and DSi yield (panels b, d, f, h, j, l, n, and p) summarized across all rivers within each biome. Trends are reported as Sen slope values (left *y*-axis). Positive values signify increasing and negative values signify decreasing over time. Polar desert excluded because long-term record only included sampling in December and January. Temperature (blue lines) and precipitation (green lines) data are normalized to their long-term mean values (right *y*-axis) and are included to represent timing of intra-annual changes. Note differences in scales across panels.