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OH-bilder

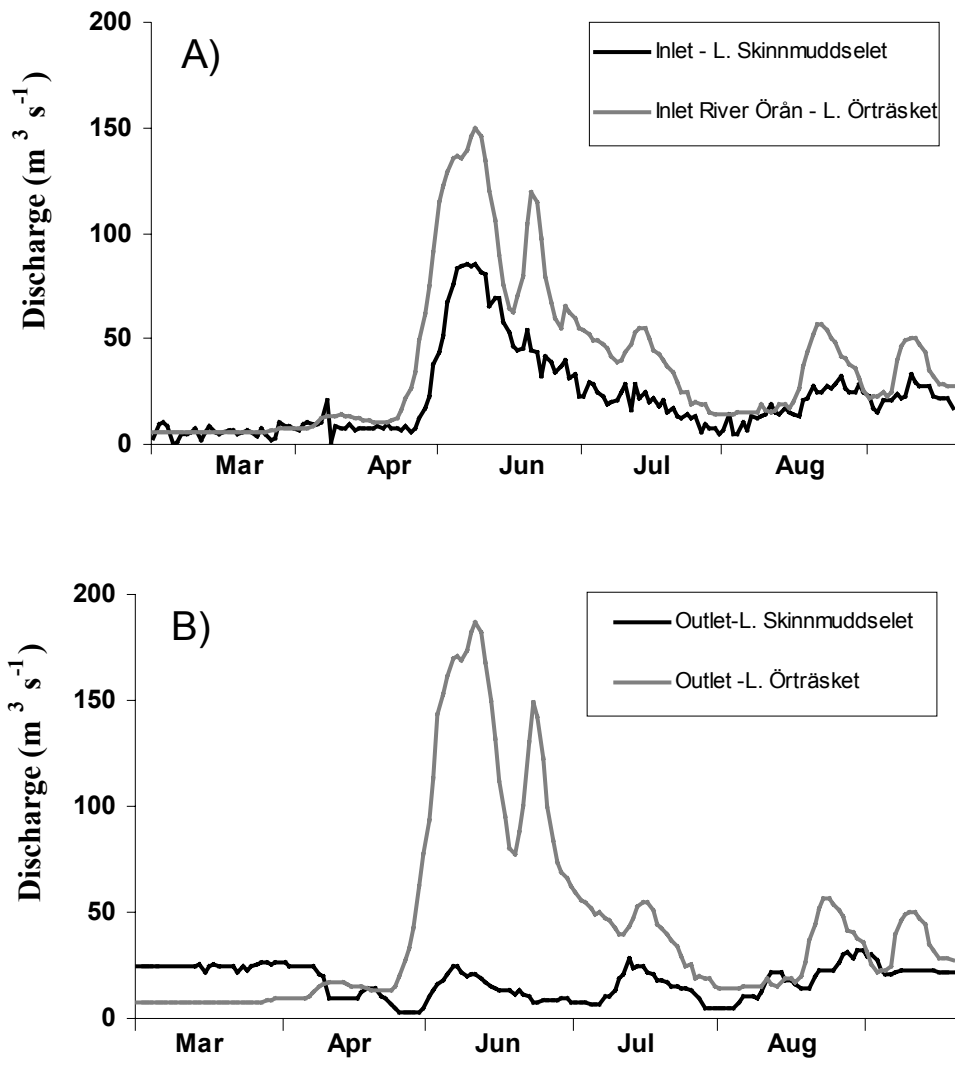


Fig. 1. Discharge from a) the inlets and b) the outlets of Lake Skinnmuddselet and Lake Örträsket.

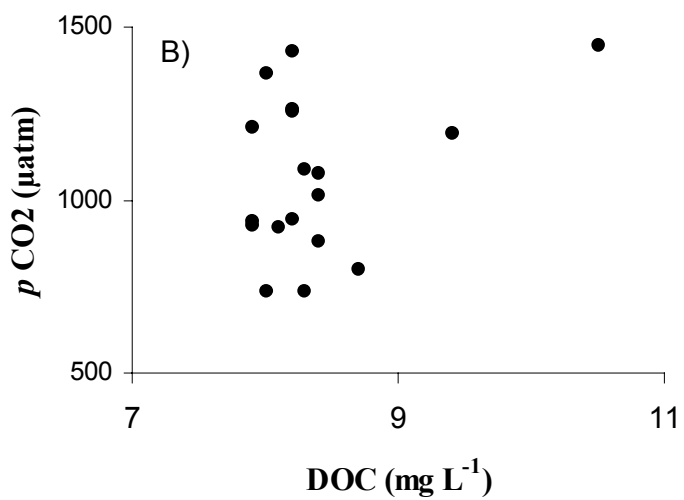
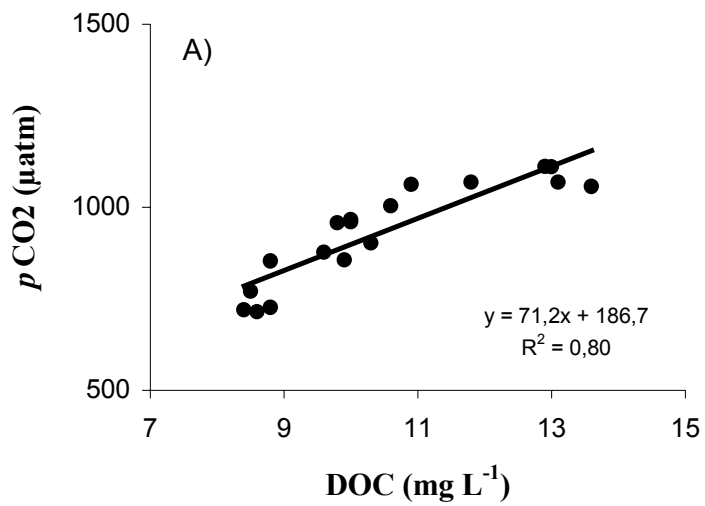


Fig. 2. Relationship between surface $p\text{CO}_2$ and DOC in a) Lake Örräsket, and b) Lake Skinnmuddselet.

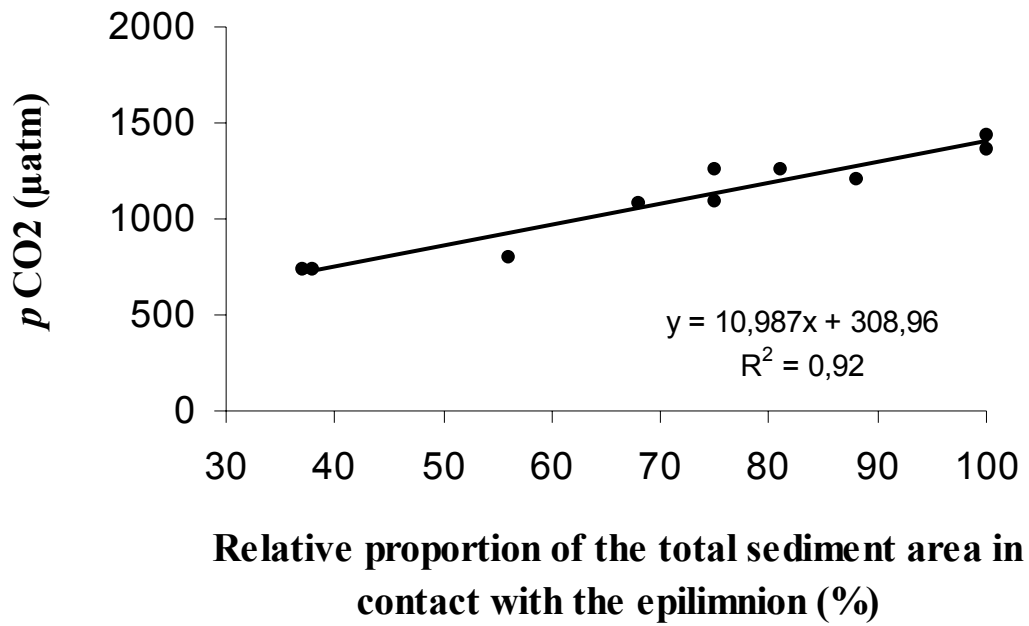


Fig. 3. Relationship between surface $p\text{DOC}$ and relative proportion of the total sediment area in contact with the epilimnion in Lake Skinnmuddselet during summer stratification. Points represent five sub-areas of L. Skinnmuddselet. Each sub-area was sampled on June 29 and on July 17.

Table 1. Physical and hydrological characteristics of Lake Skinnmuddselet and Lake Örträsket in the summer of 2001.

| | Lake Skinnmuddselet | Lake Örträsket |
|---|------------------------|-------------------|
| Catchment area (km ²) | 1400 | 2210 |
| Mean lake area (km ²) | 27 | 8 |
| Mean lake volume (Mm ³) | 170 | 170 |
| Maximum depth (m) | 20 | 64 |
| Mean depth (m) | 6,5 | 23 |
| Mean water inflow (m ³ s ⁻¹) | 20 | 33 |
| Whole lake water exchange time (days) | 110 | 61 |
| Epilimnion water exchange time (days) | 94 | 22 |

Table 2

Chemical characteristics of Lake Skinnmuddselet and Lake Ötrasket during the study period of 28 May – 19 Aug 2001. Mean values are given with ranges in parentheses.

| | Lake Skinnmuddselet | | Lake Ötrasket | |
|-----------------------------------|----------------------|----------------------|----------------------|-----------------------|
| | Epilimnion (n=39) | Hypolimnion (n=6) | Epilimnion (n=38) | Hypolimnion (n=38) |
| DIC (μM) | 120 (114-128) | 223 (199-253) | 115 (110-121) | 167 (137-197) |
| CO ₂ (μM) | 56 (50-62) | 141 (128-157) | 50 (34-65) | 118 (88-153) |
| DOC (mg L^{-1}) | 8.5 (7.9-10.8) | 8.2 (7.6-10.7) | 10.5 (8.4-13.6) | 10 (9.2-10.5) |
| ABS (430 nm, 5cm cyv) | 0.15 (0.13-0.21) | 0.16 (0.14-0.21) | 0.19 (0.15-0.31) | 0.19 (0.18-0.23) |
| pH | 6.3 (6.2-6.5) | 6.1 (5.9-6.3) | 6.4 (5.2-6.7) | 5.9 (4.4-6.3) |
| Total-N ($\mu\text{g L}^{-1}$)* | 460 | | 532 | |
| Total-P ($\mu\text{g L}^{-1}$)* | 15 | | 17 | |
| Chl-a ($\mu\text{g L}^{-1}$)* | 4 | | 2.2 | |

* Values originate from one sampling occasion in the summer of 2001 (Algesten unpublished data)

Table 3. Lake carbon balances (g C m^{-2}) for L. Skinnmuddselet (L. S) and Lake Örräsket (L. Ö) during the period 28 May – 19 Aug, 2001. Values in parentheses are given in tonnes C for the whole lakes.

| | | Pool ¹ | Δ Pool ² | Input ³ | Output | | | Retention ⁷ | Internal Net Supply | | |
|-------|-----------------|-------------------|----------------------------|--------------------|---------------------|-----------------------|--------------------|------------------------|---------------------|--------------------|------------------------|
| | | | | | Outlet ⁴ | Emission ⁵ | Total ⁶ | | Total ⁸ | Water ⁹ | Sediment ¹⁰ |
| L. S. | DOC | 53 (1430) | 12.2 (330) | 46.7 (1260) | 36.7 (990) | | 36.7 (990) | 10 (270) | 2.2 (60) | | |
| L. S. | DIC | 10 (270) | 2.2 (60) | 8.5 (230) | 7.8 (210) | 23.9 (645) | 31.7 (855) | -23.1 (-625) | 25.3 (685) | | |
| L. S. | CO ₂ | 5.2 (140) | 1.1 (30) | 3.3 (90) | 3.7 (100) | 23.9 (645) | 27.6 (745) | -24.3 (-655) | 25.3 (685) | 5.3 (143) | 20 (542) |
| L. Ö. | DOC | 205 (1640) | -10 (-80) | 350 (2800) | 350 (2800) | | 350 (2800) | 0 | -10 (-80) | | |
| L. Ö. | DIC | 35 (280) | 7.5 (60) | 47.5 (380) | 50 (400) | 21.3 (170) | 71.3 (570) | -23.8 (-190) | 31.3 (250) | | |
| L. Ö. | CO ₂ | 22.5 (180)) | 6.3 (50) | 15 (120) | 18.7 (150) | 21.3 (170) | 40 (320) | -25 (-200) | 31.3 (250) | 20.5 (164) | 10.8 (86) |

¹ Lake water pool of carbon

² Change in lake water pool from day 0 to day 84

³ Input of carbon via the inlets

⁴ Output of carbon via the outlet

⁵ Output (emission) of carbon over the water surface

⁶ Total output of carbon (Outlet + Emission)

⁷ Retention (Input-Total Output)

⁸ Total Internal Net Supply (Δ Pool-Retention)

⁹ Internal Net Supply from water column mineralization (10% of the DOC-pool (Pool); based on results from the study by Jonsson et al. [17])

¹⁰ Internal Net Supply from sediment mineralization (Total Internal Net Supply – Internal Net Supply from water column mineralization)

Table 1. Physical, chemical and biological characteristics of the sampled reservoirs (Aug-Sep 2000 or/and Jul-Aug 2002) in the three different regulated river systems in Sweden. Data from the reservoirs L. Skinnmuddselet, located within the regulated R. Gideälven, from the study by Åberg *et al.* [submitted] is also included. (nm=not measured; R.L.=River Luleälven, R.U. =River Umeälven, R.I.=River Indalsälven; R. G.=River Gideälven; S-CO₂-sat.=Surface CO₂-saturation; S-pCO₂=Surface pCO₂; S-CO₂=Surface-CO₂; S-DIC=Surface DIC; B-CO₂=Bottom-CO₂; B-DIC=Bottom-DIC).

| Reservoir/Lake | Altitude (m.a.s.l.) | Conductivity ($\mu\text{S cm}^{-1}$) | DOC (mg L^{-1}) | pH | Chl-a ($\mu\text{g L}^{-1}$) | Tot-P ($\mu\text{g L}^{-1}$) | Tot-N ($\mu\text{g L}^{-1}$) | S-CO ₂ -sat. (%) | S-pCO ₂ (μatm) | S-CO ₂ (μM) | S-DIC (μM) | B-CO ₂ (μM) | B-DIC (μM) |
|-----------------------------------|------------------------|---|-------------------------------|-----|-----------------------------------|-----------------------------------|-----------------------------------|--------------------------------|---|--|----------------------------|--|----------------------------|
| R. L. Parkijaure | 297 | 21 | 2.8 | 7.0 | 1.4 | 7.3 | 52 | 128 | 474 | 27 | 190 | 58 | 187 |
| R. L. Tjaktajaure | 477 | 17 | 1.7 | 6.6 | 2.5 | 6.2 | 58 | 121 | 434 | 23 | 118 | 40 | 140 |
| R. L. Skalka | 297 | 25 | 2.8 | 6.8 | 1.7 | 3.1 | 44 | 110 | 393 | 20 | 177 | 24 | 185 |
| R. L. Stora Lulevattnet | 372 | 23 | 1.9 | 6.8 | 1.1 | 3.3 | 30 | 108 | 382 | 20 | 161 | 23 | 160 |
| R. L. Tjämätisjaure | 288 | 25 | 2.2 | 7.0 | 1.1 | 3.1 | 53 | 87 | 338 | 18 | 180 | 24 | 190 |
| R. L. Akkajaure | 453 | 28 | 1.2 | 7.0 | 1.1 | 3.1 | 13 | 116 | 393 | 24 | 197 | 23 | 199 |
| R. L. Satihaure | 457 | 25 | 2.2 | 6.7 | 1.1 | 4.7 | 73 | 131 | 452 | 27 | 182 | 35 | 199 |
| R. U. Storuman | 349 | 32 | 2.7 | 7.2 | 0.9 | 2.8 | 65 | 120 | 442 | 22 | 221 | 36 | 238 |
| R. U. Överuman | 520 | 27 | 1.5 | 6.5 | 1.1 | 1.8 | 39 | 104 | 370 | 21 | 194 | 33 | 221 |
| R. U. Abelvattnet | 668 | 27 | 1.4 | 7.1 | 0.8 | 4.4 | 81 | 100 | 340 | 19 | 182 | 44 | 218 |
| R. U. Gardiken | 395 | 33 | 2.4 | 7.0 | 1.0 | 3.2 | 73 | 126 | 461 | 24 | 236 | 45 | 314 |
| R. U. Ajaure | 441 | 32 | 1.8 | 6.8 | 1.0 | 7.2 | 74 | 126 | 442 | 23 | 223 | 48 | 276 |
| R. U. Storjuktan | 412 | 33 | 3.5 | 7.0 | 1.9 | 6.4 | 117 | 141 | 525 | 27 | 260 | 55 | 294 |
| R. U. Gautan | 439 | 29 | 2.1 | 7.1 | 0.3 | 2.3 | 51 | 107 | 391 | 21 | 230 | 49 | 326 |
| R. U. Stora Björkvattnet | 395 | 36 | 1.9 | 6.9 | 0.8 | 3.0 | 123 | 99 | 355 | 18 | 242 | 36 | 290 |
| R. I. Storsjön | 293 | 42 | 4.2 | 7.2 | 0.7 | 3.1 | 156 | 121 | 439 | 21 | 304 | 35 | 419 |
| R. I. Juveln | 395 | 20 | 3.3 | 5.8 | 1.3 | 4.4 | 108 | 131 | 452 | 24 | 83 | 41 | 121 |
| R. I. Kallsjön | 383 | 18 | 4.7 | 6.5 | nm | 2.4 | 65 | 118 | 437 | 25 | 113 | 36 | 131 |
| R. I. Torrön | 418 | 16 | 3.2 | 6.5 | 1.1 | 1.5 | 93 | 111 | 373 | 20 | 75 | 38 | 104 |
| R. I. Korsvattnet | 745 | 8 | 1.9 | 5.9 | 0.6 | 1.4 | 57 | 108 | 403 | 23 | 40 | 31 | 48 |
| R. I. Anjan | 424 | 16 | 3.7 | 6.6 | 0.8 | 5.2 | 133 | 156 | 534 | 29 | 75 | 46 | 123 |
| R. I. Häckren | 493 | 16 | 2.6 | 6.8 | 1.4 | 4.4 | 54 | 113 | 407 | 20 | 106 | 40 | 129 |
| R. I. Stor-Burvattnet | 566 | nm | 2.0 | 6.3 | 0.3 | 3.7 | 125 | 117 | 420 | 24 | 42 | nm | 50 |
| R. I. Stor-Mjölkvattnet | 554 | nm | 2.0 | 6.3 | 0.5 | 4.1 | 121 | 115 | 414 | 23 | 44 | nm | 54 |
| R. G. ¹ Skinnmuddselet | 283 | nm | 8.5 | 6.3 | 4 | 15 | 460 | 290 | 940 | 56 | 120 | 141 | 223 |

¹Data from Åberg *et al.* [submitted]

Table 2. Change in lake surface area due to regulation, total energy production, mean DOC- and surface $p\text{CO}_2$ concentration, CO_2 -emission before and after regulation during the ice-free season, and emission of CO_2 during winter from all reservoirs in seven regulated rivers in northern Sweden.

| | R. Ljusnan/Voxnan | R. Ljungan | R. Indal | R. Ångerman | R. Ume | R. Skellefte | R. Lule | Total |
|---|----------------------|---------------|-------------|----------------|-----------|-----------------|------------|--------|
| Surface area before regulation (km^2) | 210 | 134 | 1176 | 854 | 360 | 817 | 574 | 4125 |
| Max surface area after regulation (km^2) | 371 | 183 | 1283 | 1043 | 509 | 947 | 928 | 5264 |
| Flooded area (km^2) | 161 | 49 | 107 | 190 | 149 | 130 | 354 | 1140 |
| Electricity production (TWh y^{-1}) | 3.7 | 2.3 | 9.6 | 11.3 | 7.4 | 4.2 | 13.6 | 52 |
| Flooded area/Electricity production ($\text{km}^2 \text{TWh}^{-1} \text{y}^{-1}$) | 44 | 21 | 11 | 17 | 20 | 31 | 26 | |
| DOC (mg L^{-1}) | 6 | 4 | 3 | 3 | 2 | 3 | 2 | |
| $p\text{CO}_2$ (μatm) | 638 | 532 | 485 | 481 | 411 | 455 | 408 | |
| Emission of CO_2 ($\text{mmol m}^{-2}\text{d}^{-1}$) | 11 | 7 | 5 | 5 | 2 | 4 | 2 | |
| Ice-free season (d) | 200 | 190 | 210 | 190 | 180 | 180 | 160 | |
| Emission of CO_2 before regulation (ice-free season) (tonnes) | 21837 | 8440 | 73859 | 35664 | 6951 | 9160 | 5303 | 161214 |
| Emission of CO_2 during regulation (ice-free season) (tonnes) | 37275 | 10918 | 78972 | 42851 | 10804 | 11949 | 7408 | 200177 |
| Emission of CO_2 during ice-free season due to regulation (tonnes) | 15438 | 2478 | 5113 | 7187 | 3853 | 2789 | 2105 | 38963 |
| Emission of CO_2 during emptying (January-May) of the reservoirs (tonnes) | 994 | 539 | 2108 | 1422 | 868 | 901 | 593 | 7425 |

Table 3. Flooded land area, CO₂-emission, CO₂-emission per unit of flooded land area, total energy production, flooded land area per unit of energy production, and CO₂-emission per unit of energy production, respectively in the seven regulated rivers in northern Sweden. Data from reservoirs in the boreal zone of Canada and from Swedish combustion plants are also included.

| | Flooded Area (km²) | CO₂-Emission (MtCO₂ y⁻¹) | CO₂-emission/ Flooded Area (ktCO₂ km⁻²) | Energy prod. (TWh y⁻¹) | Flooded area / Energy prod. (km² TWh⁻¹ y⁻¹) | CO₂-emission/ Energy prod. (MtCO₂ TWh⁻¹) |
|---|--|--|---|--|---|--|
| <u>Swedish regulated rivers</u> | | | | | | |
| R. Ljusnan/Voxnan | 161 | 0.016 | 0.10 | 3.7 | 44 | 0.004 |
| R.Ljungan | 49 | 0.003 | 0.07 | 2.3 | 21 | 0.001 |
| R. Indal | 107 | 0.007 | 0.07 | 9.6 | 11 | 0.001 |
| R. Ångerman | 190 | 0.009 | 0.05 | 11.3 | 17 | 0.001 |
| R. Ume | 149 | 0.005 | 0.04 | 7.4 | 20 | 0.001 |
| R. Skellefte | 130 | 0.004 | 0.03 | 4.2 | 31 | 0.001 |
| R. Lule | 354 | 0.003 | 0.01 | 13.6 | 26 | 0.0002 |
| Total* or Mean | 1140* | 0.05* | 0.05 | 52* | 24 | 0.001 |
| <u>Canadian regulated rivers</u> | | | | | | |
| La Grande Complex ¹ | 13000 | 4.1 | 0.32 | 82 | 159 | 0.05 |
| Churchill/Nelson ¹ | 1400 | 0.28 | 0.20 | 14 | 100 | 0.02 |
| Manic Complex ¹ | 2645 | 0.80 | 0.30 | 20 | 132 | 0.04 |
| Sainte-Marguerite ¹ | 85 | 0.02 | 0.26 | 2.8 | 30 | 0.008 |
| Churchills falls ¹ | 6705 | 2.1 | 0.31 | 35 | 192 | 0.06 |
| <u>Electricity production using fossil fuels in Sweden</u> | | | | | | |
| Oil and gas | | 1.9 | | | | |
| Coal and coke | | 0.9 | | | | |
| Peat and sweepings | | 0.1 | | | | |
| Biofuel | | 0.6 | | | | |
| Total | | 3.5 | | 8.4 | | 0.4215 |

¹Data from Duchemin et al. [in press]

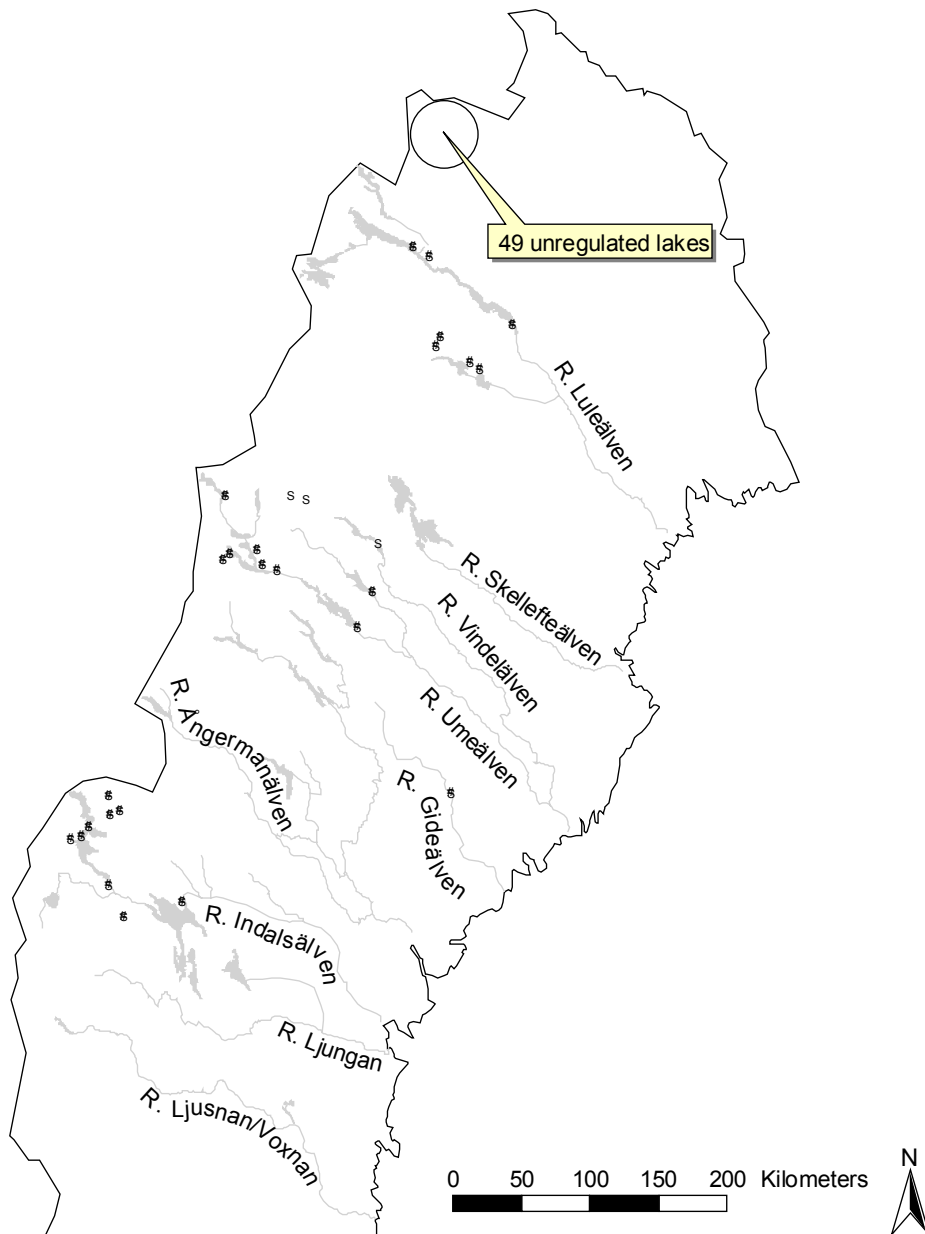


Figure 1. Map illustrating the location of the sampled reservoirs (filled circles) and the natural lakes (the letter S and the 49 unregulated lake area) and the rivers included in the national survey regarding CO₂-emission.

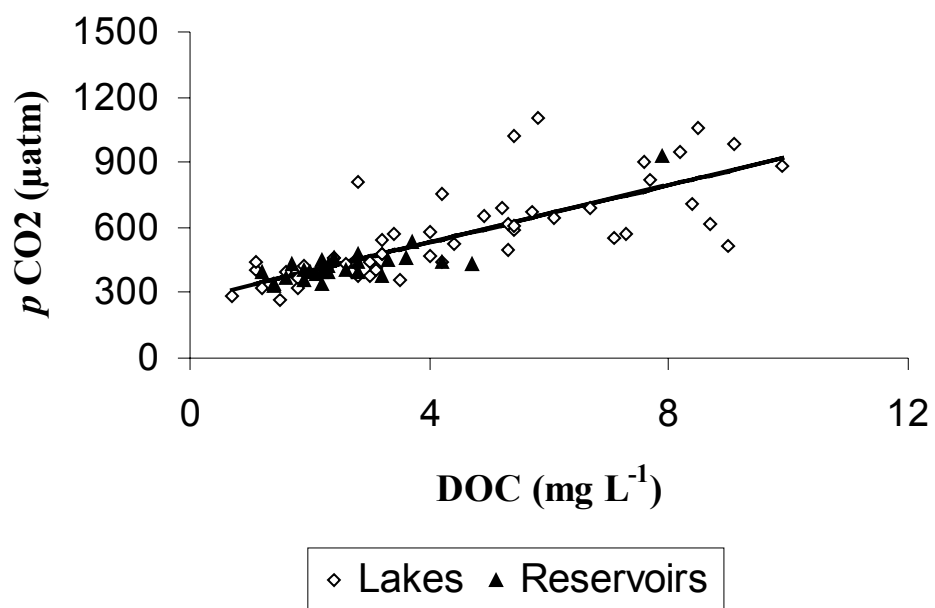


Figure 2. Relationship between DOC concentration and surface $p\text{CO}_2$ in reservoirs and natural lakes situated in the northern part of Sweden.

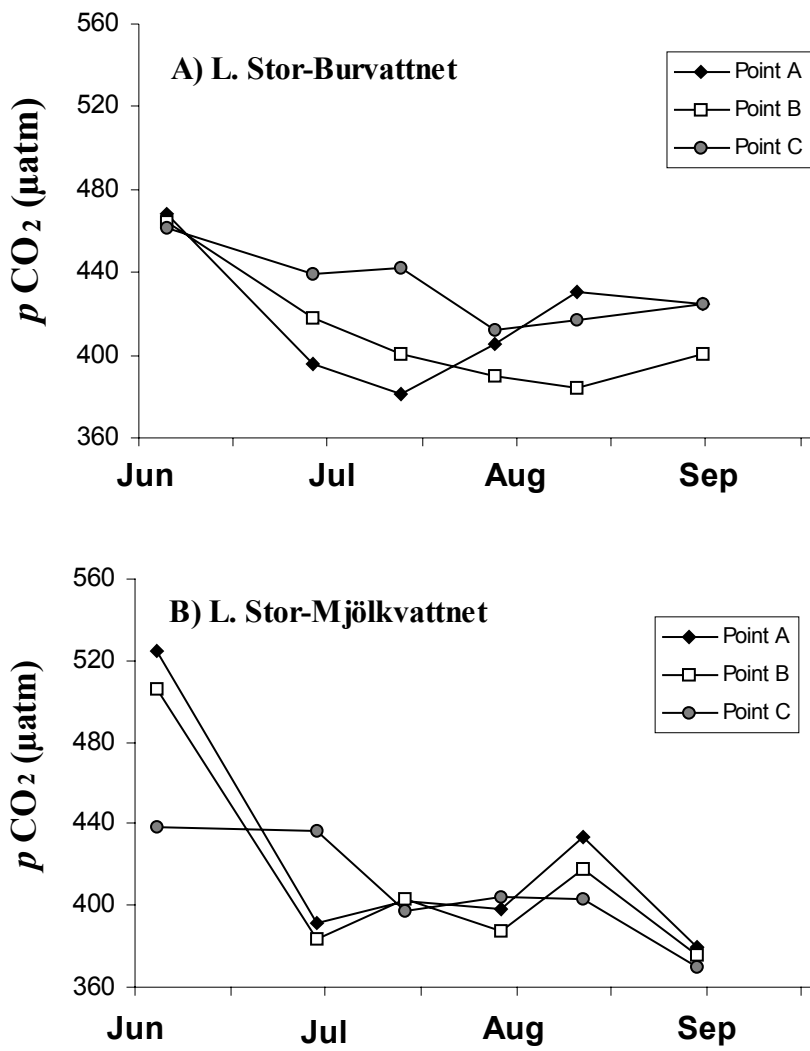


Fig 3. Seasonal variation in surface $p\text{CO}_2$ concentration at three different sampling points (A, B and C) in the reservoir A) L. Stor-Burvattnet, and B) L. Stor-Mjölkvattnet.

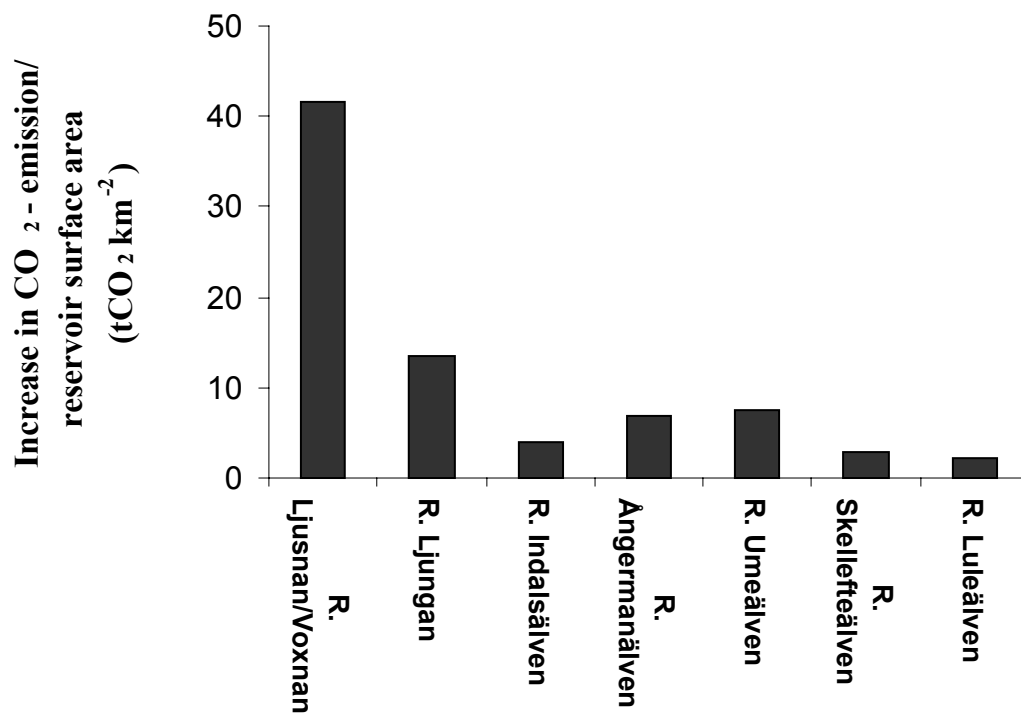


Fig 4. The increase in CO₂-emission due to regulation per unit reservoir surface area during maximal impoundment in the seven investigated river systems.

