Supplementary Information:

Landscape process domains drive patterns of CO_2 evasion from river networks

Gerard Rocher-Ros*[1], Ryan Sponseller[1], William Lidberg[2], Carl-Magnus Mörth[3], Reiner Giesler[1]

[1]*Climate Impacts Research Centre, Department of Ecology and Environmental Science, Umeå University, 98107 Abisko, Sweden*

[2]*Department of Forest Ecology and Management, Swedish University of Agricultural Science, 90183 Umeå, Sweden*

[3]*Department of Geological Sciences, Stockholm University, Stockholm, Sweden*

Corresponding Author: Gerard Rocher-Ros (gerard.rocher@umu.se)

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Text S1: Modelling and validating the gas transfer velocity

Validation of the k_{600} measurements

We estimated the k_{600} following eq. 3, as in Raymond et al. (2012). This relationship had the higher correlation with k_{600} (R^2=0.76) in the study by Raymond et al. (2012), and while the authors caution about its use in large rivers due to the depth term, we think is appropriate in this catchment with steep small streams and shallow depths. Parallel to this study, we also obtained independent estimates of gas transfer velocity using the night-time regression method from dissolved oxygen loggers deployed at seven sites within this same stream network (Gerard Rocher-Ros, unpublished data). We compared the k_{600} obtained from eq. 3 applied to these seven sites with estimates of k_{600} from the night-time regression method (Figure S4) and found a strong correlation (R^2=0.88, $p<0.0005$), supporting that our estimates of k_{600} are comparable.

Calculation of k_{600} for the GLORICH database

We used the GLORICH database (Hartmann et al. 2014) to explore the universality of the relationship between k_{600} and pCO_2. The GLORICH database contains a wide array of physicochemical parameters and catchment properties for 17000 streams and rivers across the world. For the sites with pCO_2 data available (n=7009), we calculated the median pCO_2 if several measurements were available for a given site. After excluding sites with a median pCO_2 > 40000 ppm and unknown coordinates we obtained a total of 4790 sites. To calculate k_{600} for these sites we modelled the water velocity and the reach slope, and then used eq. 5 from Raymond et al., (2012): $k_{600} = -2.02 + S\times V\times 2841$. Velocity was estimated with stream hydraulic relationships with discharge (Raymond et al. 2012), as: $\log(V) = -1.64 + 0.285\times\log(Q)$. For sites where Q was not available (n=2929), we approximated Q as the product of runoff and catchment area. This approach predicted observed Q for the remaining sites (n=1884) with an R^2=0.97 and has been used in other exercises (Lauerwald et al. 2015). The reach slope was determined as the elevation difference divided by the distance of the reach. For each site, we downloaded the DEM covering each site hosted in the Amazon Web Services (https://registry.opendata.aws/terrain-tiles/) using the "*elevatr*" package in R (version 3.5.1) with a pixel resolution ranging from 9-19 m, depending on the source. Then we found the lowest elevation around the site in a radius of 500 m, and assumed that the river downstream crosses that point (Figure S2). The reach slope then is the elevation difference between the site and the lowest elevation divided by the distance. The code to obtain slopes in a global database can be found in this Github repository: https://github.com/rocher-ros/global_slope/wiki. The k_{600} obtained by this method should be taken with caution, as it depends on velocity derived from its relationship with discharge (Raymond et al. 2012) and also with the slope calculated assuming a linear river channel within 500 m, which in small streams can cause an overestimation.

Text S2: Stream delineation and wet area modelling

We used the ArcGIS 10 suite (ESRI 2017 Redlands, CA: Environmental Systems Research Institute) to create the maps and obtain several geographical and hydrological parameters. We delimitated the watershed using a DEM with 2 m resolution (http://www.lantmateriet.se), The stream network was obtained from existing maps, corrected using orthophoto images to delimitate the beginning of streams. For the headwaters, these delineations were ground truthed and modified based on visual observations in the field. We estimated stream area by multiplying the length of the segments by the widths measured in the field. The slope for each reach was obtained as the elevation difference between the site and the elevation 50 m above, divided by 50 m.

Wet area modelling was done by calculating the depth to water index (DTM). The DTW depends on the slope along the flow path of water in the channel, and thus is a suitable proxy to the subsurface water flow (Lidberg et al. 2017). Specifically, the DEM generated by the Swedish Mapping, Cadastral and Land Registration Authority using LiDAR was used to model wet areas near streams. This was done in three steps. First the DEM was hydrologically corrected by breaching, to avoid artificial sinks. Next, raster stream networks were extracted from the hydrologically correct DEM using Deterministic-8 and a stream initiation threshold of 4 ha. Finally, the DTW was calculated along the least-cost-path described by:

$$DTW(m) = \left[\sum \frac{dz_i}{dx_i} a_i \right] xc \qquad (6)$$

Where dz/dx is the slope of a cell along the least-elevation path, i is a cell along the path, a_i equals 1 when the path crosses the cell parallel to cell boundaries and $\sqrt{2}$ when it crosses diagonally; xc represents the grid cell size (m). Wet areas were defined as any cell with a DTW< 1. For each site, the % of wet area was computed as following: First, the area draining into each site was calculated as the difference of catchment area between this and the previous site in the river network. Then, % of wet area was obtained as the fraction of the draining area with a DTW< 1 multiplicated by 100.

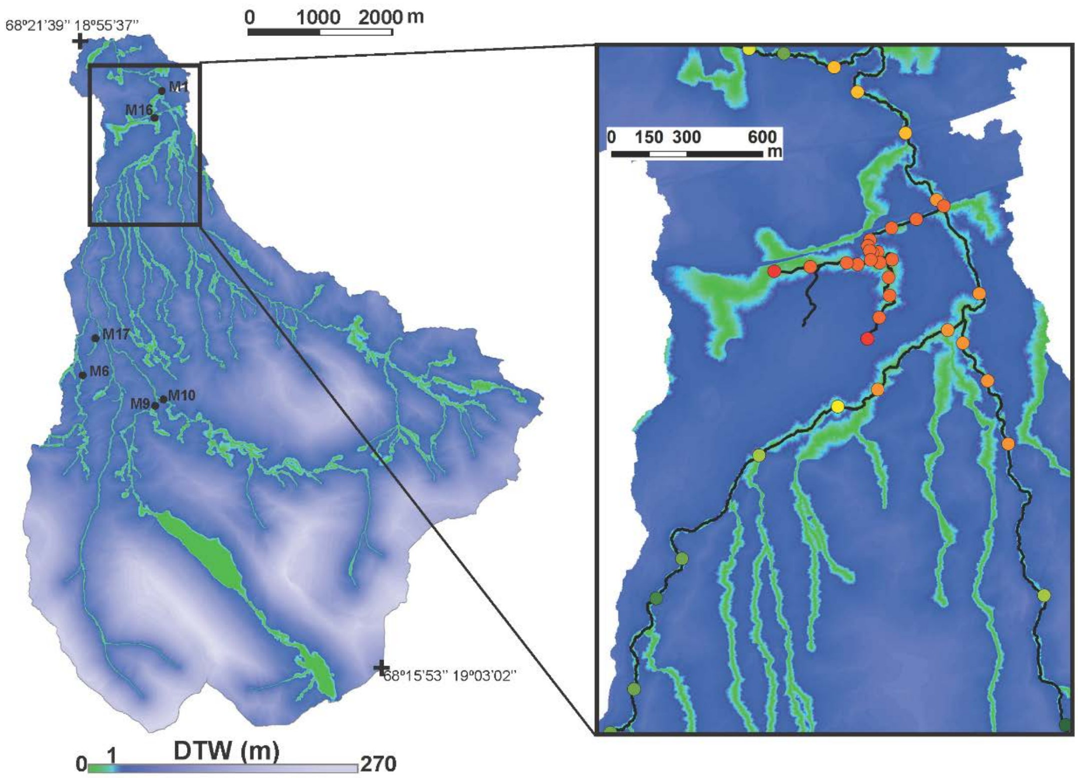

Figure S1: Wetness maps for the Miellajokka catchment. The color scale represents the distance to water (DTW) in meters. The color blue-green color threshold corresponds to a DTW of 1 m, the limit used to determine an area as "wet" and used in this study. The different sites with monitoring stations are also shown. The right panel shows in detail the lower part of the catchment, showing the streams and the sites with $p\mathrm{CO_2}$ in the same color scale as in figure 1.

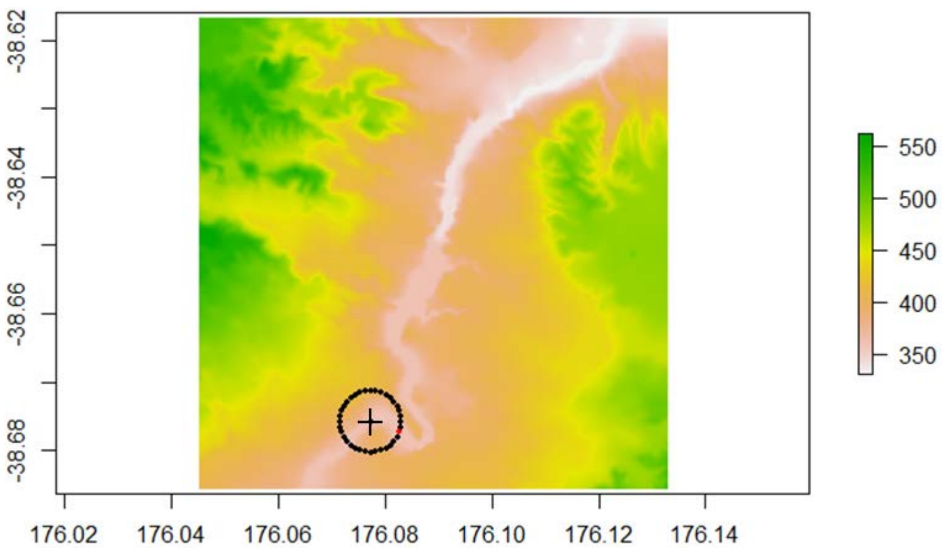

Figure S2: Estimating the channel slope for the sites in the GLORICH database. This figure illustrates the topographic map of one site, with the color scale showing elevation in meters. For each site within the database (cross) we extracted the elevation of all locations around 500 m of the site (black dots). By finding the location with the lowest elevation (red dot), we assumed that it corresponds to the stream channel downstream. And calculated the slope as the elevation difference divided by the distance.

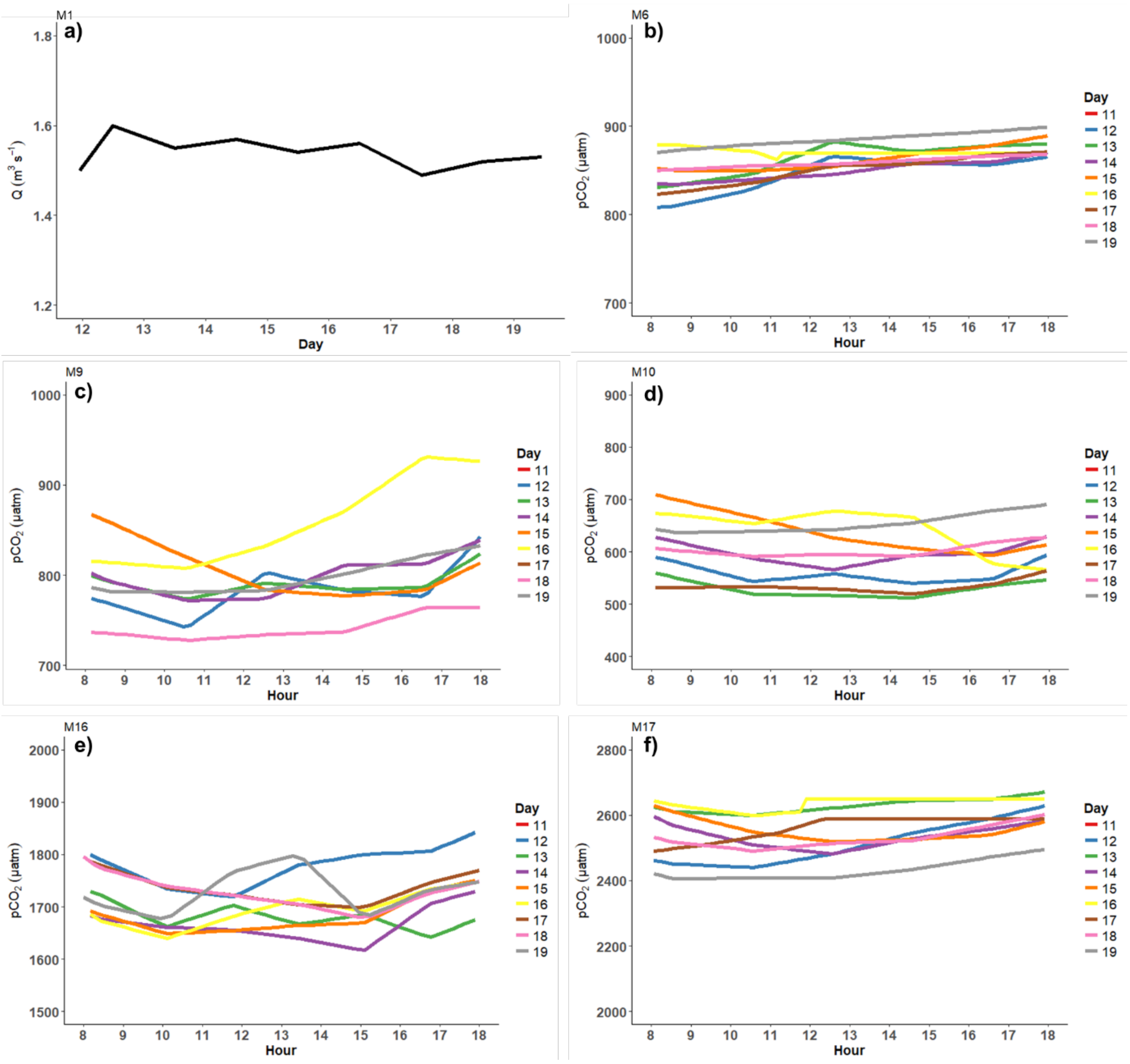

Figure S3. Continuous measurements at 6 sites in the catchment shown in figure S1, which is part of another study (Rocher-Ros, In prep). (a) shows the daily discharge during the sampling days at site M1, close to the outlet of the catchment. Panels b-f represent hourly measurements of $p\text{CO}_2$ at different sites, for the hours when the sampling was performed and for each day of the sampling campaign (8 to 18h). $p\text{CO}_2$ was measured using a eosGP sensor (http://www.eosense.com/products/eosgp/) connected to a Campbell CR1000 data logger (https://www.campbellsci.com/cr1000). The sensor was calibrated using standard gasses, with an accuracy estimated to be <3% according to the manufacturer. The $p\text{CO}_2$ did not vary consistently within the day, supporting that our spatial measurements are site specific and not an artefact due to the time of sampling. The variation across days was generally below 150 ppm although in some sites it could be as high as 200 ppm (M17).

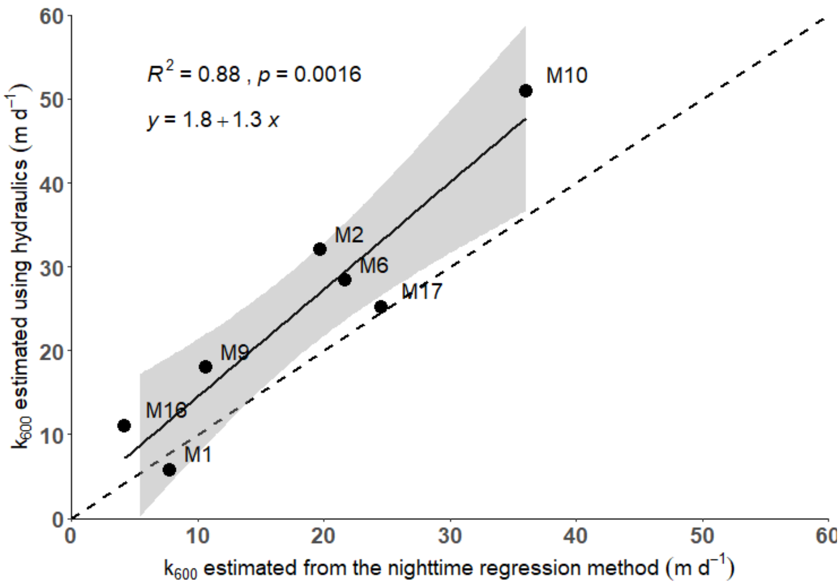

Figure S4. Comparison of the k_{600} obtained using eq. 2 from Raymond et al., (2012), based on hydraulic measures, with the k_{600} obtained from the night-time regression method of dissolved oxygen time series. The 95% confidence interval of the slope was 0.87-1.68, thus without significant differences from a slope of 1. In the 7 sites in figure S1 we also performed continuous measurements of O (Rocher-Ros, in prep.), the drop of oxygen concentration at the nightfall can be used to infer the gas transfer velocity (Odum, 1956). Performing the night-time regression for each day and using the best regressions, we constructed a model to predict k_{600} with discharge (details about the calculations can be found in: https://github.com/rocher-ros/nighttime_regression_multiple)

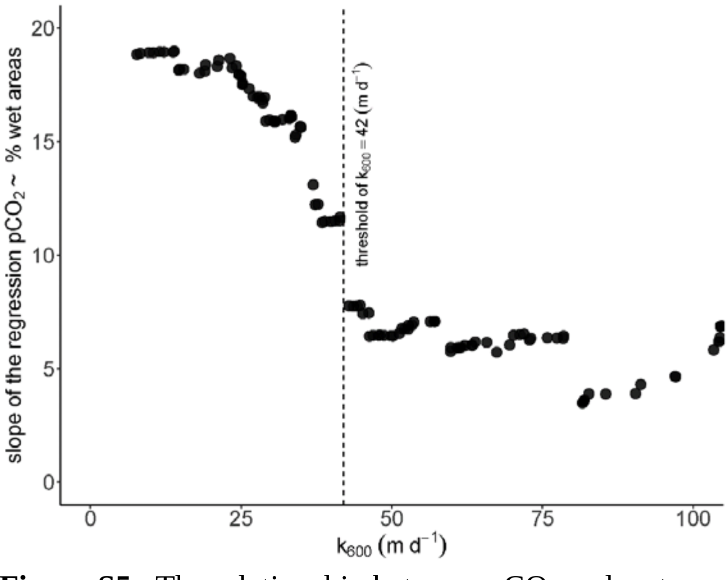

Figure S5. The relationship between pCO_2 and wet areas is weaker with higher k600, but we wanted to find which value was more significant. To assess at which threshold pCO_2 is strongly related to the % of wet areas in the catchment (figure 2b), we performed several linear regressions between pCO_2 and wet areas, for a decreasing range of k_{600}. This figure represents the slope of these linear regressions for a given range defined as k_{600}:max(k_{600}). We find that the slope between pCO_2 and wet areas decreases abruptly when k_{600} is about 42 m d^{-1}, and thus we interpret that above that k_{600} threshold the effect of wet areas on pCO_2 is masked by the high gas transfer. The results are similar by looking at the strength of the relationship (R^2).

Table S1. Physical characteristics of the stream network in the Miellajokka catchment, grouped by Strahler order. For length and surface the total values are reported, while for the other parameters the median is shown and 10th-90th percentile in parentheses.

Strahler order	***n***	***Length (m)***	***Surface (m^2)***	***Width (m)***	***Depth (m)***	***Slope (unitless)***	***Velocity ($m\ s^{-1}$)***	***Discharge ($m^3\ s^{-1}$)***	***k_{600} ($m\ d^{-1}$)***
1	74	11805	23119	1.30 (0.47-3.00)	0.13 (0.07-0.28)	0.053 (0.014-0.141)	0.29 (0.07-0.66)	0.05 (0.01-0.15)	40 (16-115)
2	50	15492	53923	2.90 (1.55-5.42)	0.22 (0.14-0.39)	0.049 (0.016-0.088)	0.59 (0.31-0.91)	0.32 (0.12-0.63)	75 (27-151)
3	36	14072	56356	4.00 (2.05-5.46)	0.29 (0.13-0.40)	0.06 (0.017-0.093)	0.62 (0.22-0.95)	0.67 (0.20-1.33)	95 (20-223)
4	9	3296	18202	5.72 (4.58-5.98)	0.38 (0.28-0.43)	0.01 (0.006-0.023)	0.96 (0.86-0.98)	1.45 (1.16-1.49)	24 (5-59)