WebPanel 1. Re-evaluation of global CO_2 fluxes from inland waters

Published estimates of the global flux of carbon dioxide (CO_2) outgassing from inland surface waters have been calculated via averages of partial pressures of dissolved CO_2 (pCO_2) concentrations, gas exchange velocities (k), and areal extent of inundation that are biased toward northern latitudes (Cole and Caraco 2001; Cole *et al*. 2007; Battin *et al*. 2009; Tranvik *et al*. 2009). Recent re-evaluations of temperature dependencies of these factors and more balanced consideration of the tropics and of wetlands all contribute to a need to further increase estimates of regional and global CO_2 outgassing fluxes. Here we discuss each of these factors, and provide support for our revised global CO_2 outgassing estimates provided in Table 1.

Partial pressures of dissolved CO_2 are a function of organic carbon mineralization fluxes minus outgassing fluxes from the water surface (see supplementary discussion in Mayorga *et al.* 2005). Two studies have shown that pCO_2 has a strong positive relationship with water temperature (Marotta *et al*. 2009; Kosten *et al*. 2010), reflecting the temperature dependence of respiration. The slopes of these published log-linear relationships show a 2x to 3x increase in pCO_2 for a 10˚C increase and a 4x to 7x increase in pCO_2 for a 20˚C increase. In addition, many published pCO_2 values may include underestimates because of inattention to gas evasion during sample handling, which can be rapid and substantial, before a pH, pCO_2, or dissolved inorganic carbon measurement. In Table 1, we present median pCO_2 values for each climate zone and inland water type, based on a synthesis of thousands of data points from our own measurements and data available in the literature (Alin *et al*. unpublished; Cole and Caraco 2001; Richey *et al*. 2002; Mayorga *et al*. 2005; Johnson *et al*. 2008; Marotta *et al*. 2009; Humborg *et al*. 2010).

To translate water–air CO_2 gradients to areal fluxes requires multiplication by k, which varies as a function of turbulence in the surface water and, to a lesser degree, temperature. Gas exchange velocities can be challenging to measure, and published values for CO_2 exchange velocities for streams and rivers are sparse. The few syntheses of global CO_2 evasion fluxes from fresh waters have used conservative k values of 2 to 4 cm hr^{-1} obtained from studies of lakes, where wind is often assumed to be the primary driver of surface turbulence (Cole and Caraco 2001; Cole *et al*. 2007; Table 1). Turbulence in streams and rivers is increased by flow over rough elements in channel bottoms (ie boulders, sand bars), and direct measurements of CO_2 exchange velocities in flowing waters range from 3 to 30 cm hr^{-1} (Raymond and Cole 2001; Bott *et al*. 2006; Table 1). Previous global CO_2 evasion estimates have not considered the effect of temperature on k and have implicitly assumed uniform global water temperatures similar to those in the temperate zones. For water with the same surface turbulence, a 10˚C increase translates to a 30–37% increase in k and a 20˚C increase to a 70–79% increase in k. Considering both the increased turbulence of streams and rivers and the temperature effects on k requires that we further upwardly revise current estimates of water-to-air CO_2 fluxes from inland waters. In Table 1, we present median k_{600} values – the CO_2 gas transfer velocity normalized to 20˚C in freshwater, which has a Schmidt number of 600 – for each climate zone and inland water type based on a synthesis of data from our own measurements and data available in the literature.

Remote-sensing approaches can quantify actual inundated area as a function of time (Hess *et al*. 2003; Prigent *et al.* 2007), to which areal outgassing fluxes can be directly applied for estimating spatial and temporal patterns of CO_2 gas evasion from inland waters. In Table 1, we summarize seasonally maximum inundated areas by grouping the 12 classes quantified by Lehner and Döll (2004) – each multiplied by empirically derived "undersampling factors" of 1.73, 1.22, and 1.56 for lakes, reservoirs, and wetlands, respectively – as developed by Downing (2009) to include inland waters smaller than the 60- to 100-m resolution of Lehner and Döll's (2004) analysis. We present the area of the large rivers class (>60–100 m width), as calculated by Lehner and Döll (2004), then estimate the small rivers and streams class (<60–100 m width) using Downing's (2009) empirically derived undersampling factor of 1.41. In Table 1, we calculate seasonally minimum inundated areas by multiplying maximum areas by the minimum-to-maximum inundation ratios developed by Prigent *et al*. (2007) for each zone, in order to account for dry season wetland retreat and cold season freezing.

Different inland water types in different climates each have characteristically different pCO_2, k_{600}, and areal gas evasion values (Table 1), with consequences to globally integrated fluxes. For example, small rivers and streams have a disproportionate global flux due to their high k_{600} values and the tropics have a disproportionate global flux due to high pCO_2 values and to higher k values after temperature corrections (Table 1). Wetlands are a particularly diverse class, with large seasonal variations in inundation. They include floodplains, swamp forests, coastal marshes, bogs, intermittent lakes, and patchy wetland complexes. Because of this complexity and seasonality, Cole *et al.* (2007) explicitly excluded wetlands from their global synthesis. We have included wetlands because most wetlands: (1) receive inputs from upland terrestrial ecosystems; (2) are hydrologically connected to downstream waters; (3) process carbon differently from upland ecosystems; (4) are highly susceptible to climate and land-use change; and (5) are not included in terrestrial carbon budgets.

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