Flux of carbon dioxide from low-order temperate streams

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Abstract

The flux, or movement, of carbon dioxide (CO_2) between bodies of water and the atmosphere has been shown to be significant when determining the net carbon balance for watersheds [2]. In this study we calculated the flux of CO_2 from two low-order temperate streams to the atmosphere. We found that all sites had a positive flux of CO_2 to the atmosphere ($F_{CO2} > 0$) and spatial trends indicated that springs are major sources of outgassing CO_2, having the highest outgassing rates that we measured (**Table 1**).

Introduction

Next to water vapor, carbon dioxide is the most important gas contributing to the effects of climate change. As the concentration of CO_2 increases in the atmosphere, the movement of carbon through the Earth's carbon reservoirs (land, ocean, and atmosphere) is affected. To better understand how these reservoirs interact we need more precise models of how carbon cycles. Historically, streams and rivers have been seen as a passive pipeline for carbon to move from land to sea, but recent work has shown that they can lose ten times more carbon to the atmosphere than they deliver to the ocean [5]. Current literature values estimate the global median outgassing of temperate streams to be 2630 g C m^{-2} yr^{-1} and their median pCO_2 (partial pressure of CO_2) to be 3500 ppm [1]. The current pCO_2 of the atmosphere is 395 ppm [6] so most streams exhibit a net flux of CO_2 outgassing to the atmosphere. By calculating CO_2 outgassing rates from more streams and as better methods of estimating outgassing are developed, the models of carbon cycling can be improved.

But where does this CO_2 come from? A variety of organic and inorganic molecules move through forests and eventually into streams. As we now know, streams do not passively carry these molecules all the way to the ocean. Some of these molecules can be sources of carbon for decomposer organisms living in the soils and streams and result in the production of CO_2 through decomposition. Groundwater dissolved organic carbon, soil decomposition and direct CO_2 fixation by root respiration also contribute to the production of dissolved CO_2 [2, 5]. This CO_2 then outgasses meters to kilometers downstream of its site of origin [5].

Above: Site SCC3 being measured for reach length and depth.

Top right: Water samples for DIC analysis were collected in beer bottles with 30 µL $HgCl_2$ added to each sample for preservation.

Bottom: Titration set-up including a Gilmont 2 mL microburet, Orion pH meter, 25 mL graduated buret, and stir plate

Study Area and Methods

The E.E.O.N. (Evergreen Ecological Observation Network) is located in a 380 ha temperate rainforest managed by The Evergreen State College and is composed of a grid of 44, 20m in diameter, long-term research plots spaced evenly apart. Seven new plots were established this summer at two different streams for intensive continued monitoring (**Fig 1**). Two additional sites (SCSp1, SCSp2) were established for use in this study with the possibility for continued monitoring. Alkalinity, concentration of all carbonic acid species (dissolved inorganic carbon [DIC]), water temperature, and flow rate of the streams were used to calculate the outgassing rate of carbon dioxide. As part of my SURF contract, the seven main sites were also measured for pH, dissolved oxygen, conductivity, salinity, macroinvertebrate abundance, length of reach, depth of water, percentage of canopy cover, slope and sinuosity.

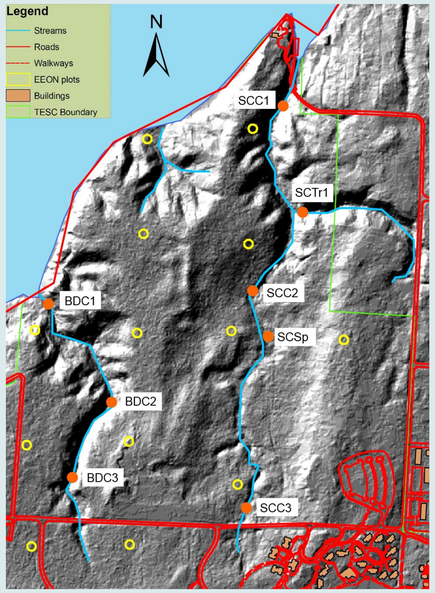
Working with limited time and budget, only seven of the nine sites were evaluated in this study. The middle two sites on the main streams (BDC2, SCC2) were excluded because they presumably provide the least unique data as they are intermediary sites between the headwaters and mouths of each stream.

Flux of CO_2 was calculated for each site using the equation:

$$F_{CO_2} = K_{GT} K_H (pCO_2{}^{w} - pCO_2{}^{atm})$$

Where K_{GT} is the gas transfer coefficient, which incorporates flow rate, K_H is Henry's Law coefficient, which incorporates water temperature, $pCO_2{}^{w}$ is the partial pressure of CO_2 in the water, which incorporates DIC, alkalinity, and water temperature and $pCO_2{}^{atm}$ is the global average partial pressure of CO_2 in the atmosphere for the month of September 2014 as measured by the Mauna Loa observatory and reported by the National Oceanic and Atmospheric Administration (NOAA).

Alkalinity was determined by titrating three replicates (one analytical) of 0.45µm filtered water from each site with standardized sulfuric acid. Flow rates were measured with a Swoffer meter at least four times per site. Water temperatures were measured with a YSI meter. Samples for DIC were analyzed by the chemical oceanography lab at Oregon State University.



Results

Site	Alkalinity (µeq L^{-1})	DIC (µmol L^{-1})	Water Temperature (°C)	Flow Rate (cm s^{-1})	$pCO_2{}^{w}$ (µatm)	K_{600} (cm hr^{-1})	F_{CO2} (µmol m^{-2} s^{-1})
BDC1	1082	1124	13.1	67	916	37.3	2.17
BDC3	1136	1192	12.0	41	1165	28.2	2.44
SCC1	1629	1727	11.9	111	1995	52.7	9.49
SCC3	1851	1915	13.8	43	1466	28.9	3.45
SCSp1	1256	1480	10.5	43*	4251	28.9	12.61
SCSp2	1261	1913	10.3	43*	12278	28.9	38.90
SCTr1	1059	1271	11.8	42	4223	28.5	12.30

Table 1. Calculated F_{CO2} and related values for each site (excluding BDC2 and SCC2). *Flow rate for SCSp1 and SCSp2 could not be measured, SCC3 flow rate was used as an approximation.

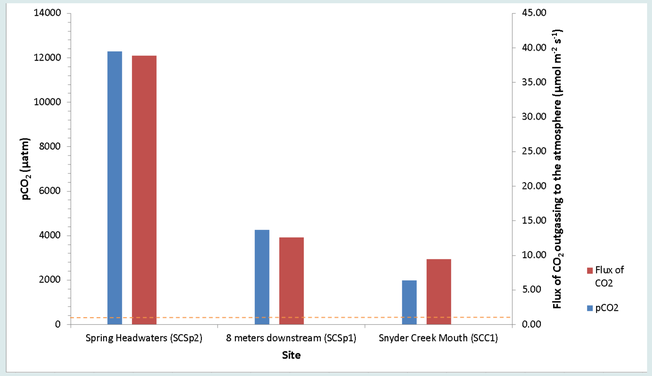


Figure 2. Spatial trends in F_{CO2} and pCO_2 starting at the spring headwaters and ending at the mouth of Snyder Cove Creek. The orange dotted line represents atmospheric pCO_2 as a frame of reference.

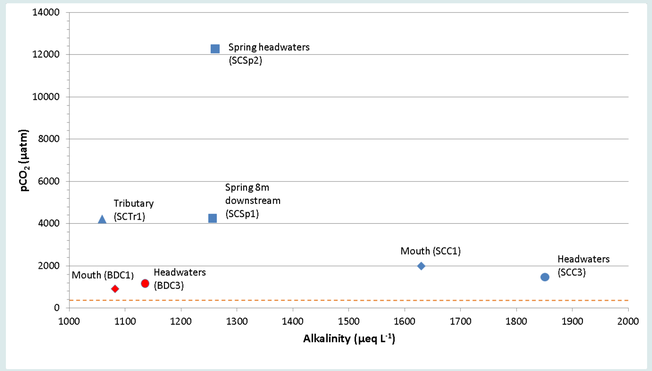


Figure 3. Alkalinity as a function of pCO_2. Each data point is a different field site with Snyder Cove Creek sites in blue and Barking Dog Creek sites in red. The shapes denote the type of site with circles representing the headwaters, diamonds representing mouths, squares representing the spring and the triangle representing the tributary. The orange dotted line represents atmospheric pCO_2 as a frame of reference.

Figure 1. (Left) Map of northern portion of E.E.O.N. Seven new stream sites are marked by orange circles. The marker labeled "SCSp" represents the two spring sites. The Barking Dog Creek drainage basin comprises the western side of the forest and the Snyder Cover Creek drainage basin, which includes the water draining from the main campus, comprises the eastern side of the forest.

Implications and Future Work

- All sites have a positive flux of CO_2 to the atmosphere ($F_{CO2} > 0$) (**Table 1**).
- There is a spatial trend of decreasing levels of F_{CO2} and pCO_2 as the stream water flows away from the spring headwaters (**Fig 2**). This trend is likely a result of rapid outgassing of groundwater-derived CO_2 as it emerges from the spring [3].
- Both of the Barking Dog Creek sites have similarly low alkalinity (1.082, 1.136 meq L^{-1}) and pCO_2 values (916, 1165 µatm) when compared to the other sites (**Fig 3**)
- Both of the Snyder Cove Creek sites exhibited similar grouping of alkalinity (1.629, 1.851 meq L^{-1}) and pCO_2 values (1995, 1466 µatm) when compared to the other sites. (**Fig 3**) The higher alkalinity value at the headwaters is likely due to this water mostly deriving from the drainage of the cement campus, then being diluted by the water draining from the forest by the time is reaches the mouth.
- Much of the variability in pCO_2 and alkalinity is not reflected in the transition from headwater sites to mouth sites, although the influence of the high pCO_2 of the spring (12278, 4251 µatm) and tributary (4223 µatm) may be visible in the pCO_2 increase from Snyder Cover Creek's headwaters (1466 µatm) to Snyder Cover Creek's mouth (1995 µatm).
- Literature values of average F_{CO2} (5.45 µmol m^{-2} s^{-1}) [4] are of the same order of magnitude as our average calculated values (11.62 µmol m^{-2} s^{-1}), corroborating our estimates.

Sources of error include:

- Flow rates of the two spring sites could not be measured directly so SCC3 flow was used instead. This flow value is directly proportional to F_{CO2} and may have resulted in an underestimate of outgassing for the spring sites
- k_{600} was calculated using the equation for a line of best fit from Alin et al. 2011 [4], relating streams' flow rates to outgassing of CO_2 (R^2= 0.41, p=0.005)
- To simplify the equations necessary to calculate pCO_2 and F_{CO2} carbonate alkalinity was used rather than total alkalinity. This excludes a small portion (≤4%) of the total chemical species contributing to alkalinity.

Some possible directions for future studies include:

- Evaluating spatial and temporal trends of pCO_2 and F_{CO2}
- Determining sources of dissolved CO_2
- Elucidating the factors controlling the variation in pCO_2 and F_{CO2} between the two drainage basins

References

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