QUANTIFYING THE ROLE OF HYDROLOGIC VARIABILITY IN SOIL CARBON FLUX

By

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ABSTRACT

Soil carbon (C) is the largest terrestrial carbon pool. While inputs to this system are fairly well constrained, the diverse factors driving soil C efflux remain poorly understood. Carbon in surface soils is mobilized via two distinct pathways: CO_2 gas flux and dissolved C flux. The goal of this study was to quantify the role of hydrologic variability in mobilizing carbon as gaseous and dissolved fluxes from near-surface soils, and to determine their relative magnitudes. Data were collected through 2010 and 2011 from two subalpine sites in Arizona and New Mexico. I observed no significant variability in dissolved fluxes, and these values were low at all sites. In contrast, CO_2 fluxes were large (from 0.22 g C m^{-2} d^{-1} to 5.27 g C m^{-2} d^{-1}) and varied between sites and between years. My results suggest that in arid montane forests soil carbon flux is critically linked to water availability.

1.1 INTRODUCTION

1.1 Introduction

1.1.1 The Importance of Soil Carbon to the Global Carbon Budget

As atmospheric CO_2 concentrations continue to rise, the importance of carbon sequestration has garnered increasing interest (Wigley et al. 1996, Batjes 1998, Schlesinger 1999, Barford et al. 2001, Lackner 2003, Hayes et al. 2012). Carbon is removed from the atmosphere via photosynthesis, enabling forests to take up large amounts of carbon. Significant terrestrial carbon sequestration at mid-latitudes in the northern hemisphere occurs in montane forest ecosystems (Shimmel et al, 2002). Carbon uptake via photosynthesis has been fairly well studied and eddy covariance methods provide a quantitative approach to estimating net ecosystem exchange, and to some extent, gross primary productivity and ecosystem respiration. However, it is difficult to distinguish between respiration from aboveground biomass and that from soils. Soils form the largest terrestrial carbon pool and they have high potential for sequestering atmospheric carbon, but they can also be significant sources of carbon efflux to the atmosphere. Carbon is stabilized in soils via chemical and physical mechanisms, and after entering the soil carbon pool the residence time of carbon varies from days to 1000s of years (Trumbore 1993, Torn et al. 1997, Gaudinski et al. 2000). Carbon is lost from soils via many pathways, for example dissolved and gaseous fluxes of methane (CH4); however, the primary soil C fluxes are dissolved fluxes of organic and inorganic carbon and gaseous fluxes of CO_2. Reported dissolved organic carbon (DOC) fluxes from surface soils can vary in magnitude from 5 to 84 g C m^{-2} yr^{-1} (Neff and Asner, 2001), while dissolved inorganic carbon (DIC) fluxes from surface soils vary from 2 to 48 g C m^{-2} yr^{-1} (Jones and Mulholland 1998, Kindler et al. 2011). Gaseous soil C losses are generally larger than combined organic and inorganic dissolved C fluxes, ranging from 60 to 1260 g C m^{-2} yr^{-1} (Raich and Schlesinger 1992), and can account for approximately 60-80 % of total ecosystem respiration (Law et al. 1999, Janssens et al. 2001, Milyukova et al. 2002, Barron-Gafford et al. 2011). In some systems, over half of the C fixed during the growing season in montane forested systems is lost during the winter (Monson et al. 2002, Hubbard et al. 2005, Brooks et al. 2005). Bettering our understanding of the magnitude and controls of carbon losses from ecosystems is critical for improving estimates of ecosystem carbon balance. The following sections briefly summarize current understanding of the major processes controlling terrestrial carbon balance and primary dissolved and gaseous soil carbon fluxes.

1.1.2 Terrestrial Carbon Balance: A Review

The terrestrial carbon cycle is composed of a series of pools and fluxes. Carbon (C) is taken up by plants via photosynthesis and becomes part of the aboveground biomass pool. From there it may return to the atmosphere via plant respiration, or enter the soil C pool through root exudates or as litter/detritus, where decomposition converts plant material to soil organic matter (SOM). Soil carbon is the largest terrestrial carbon pool and with above ground biomass has the potential to sequester significant quantities of atmospheric carbon. The residence time of carbon in the soil pool is highly variable. Up to half of soil carbon turns over in decades or less while other fractions have residence times up to thousands of years (Trumbore 1993, Gaudinski et al. 2000). When carbon is lost from the soil pool it can be mobilized via two pathways: (1) via soil CO_2 efflux, the sum of plant-root and microbial respiration, whereby carbon returns directly to the atmosphere as CO_2; and (2) as dissolved fluxes that are transported via moisture fluxes as water moves through the system. The terrestrial carbon balance relates the amount of carbon that is stored in a particular ecosystem (carbon pools) to the amount that enters the system and amount that is lost (carbon fluxes). Over time, this can be thought of as the change in the total carbon stored in the system.

The magnitudes of carbon pools and fluxes vary tremendously both in space and time. Variability is a function of ecosystem type (Trumbore 1993), climatic conditions (Anderson-Teixeira et al. 2011) and the geochemical composition of weathering porous media (Torn et al. 1997, Chorover et al. 2004, Mikutta et al. 2009). Comparing tropical soils in the Amazon Basin with temperate soils on the western slope of the Sierra Nevada, Trumbore (1993) observed that the tropical soils had relatively high soil carbon content (7.1 kg C m^{-2} in the top 22cm), residence times of ten years or less, and flux rates of 1.1-5.5 kg C m^{-2} yr^{-1}. The temperate soils had comparatively low soil carbon content (5.2 kg Cm^{-2} in the top 23cm), residence times that varied from tens to thousands of years, and flux rates from 0.22 - 0.45 kg C m^{-2} yr^{-1}. Temporal variability occurs on diurnal, seasonal and interannual timescales. Rates of carbon loss and uptake vary over the course of the year, with C-uptake via gross primary productivity (GPP) dominating during the growing season when plants are actively photosynthesizing, and C-loss via net ecosystem respiration (R_{eco}) dominating during the dormant season. Similarly, over the course of a single day during summer, photosynthesis outweighs respiration during daylight hours, but respiration dominates at night. The combined outcome of these processes is commonly referred to as net ecosystem exchange (NEE). Over longer timescales, there can be significant fluctuation in NEE, resulting in changes in C storage (Anderson-Teixeira et al. 2011).

Both GPP and R_{eco} have been shown to respond to climatic variables (temperature and moisture) but not necessarily in the same way or to the same extent. Over short timescales, these responses and their physiological drivers are well understood but over longer timescales they become more difficult to tease apart as R_{eco} is inherently dependent on GPP (Hogberg et al. 2001, Ryan and Law 2005, Stoy et al. 2008). Due to the distinct responses of C-uptake and C-loss to climate, the effect on carbon balance is complex. The role of climate and climate change in moderating ecosystem carbon balance will be discussed in more detail in section 1.1.5. However, first it is important to understand the mechanisms that govern soil carbon loss.

1.1.3 Soil Carbon Loss: Dissolved Carbon Flux

As water moves through the soil, it mobilizes and transports both dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC). Although total dissolved fluxes are usually small relative to gaseous fluxes, they are known to be important as sources of energy and carbon transfers from terrestrial to aquatic ecosystems (Cole et al. 2007), and in some cases DOC transport from terrestrial environments represents a substantial component of ecosystem C balance (Kling et al. 1991, 1992, Waddington & Roulet 1997). C leached from soils often eventually ends up in streams and from there may undergo chemical transformations that subsequently lead to out-gassing, thereby returning significant quantities of C to the atmosphere. The remaining fraction of C may be transported to the ocean (Cole et al. 2007). While leaching is an effective means of removing significant magnitudes of C from soils, there are many complex factors that control the rate at which this process occurs.

DOC originates from the decomposition of soil organic matter (SOM). SOM is comprised of organic residues including undecayed plant and animal tissues and their partially decomposed products (litter), soil biomass (live microbial tissue including bacteria, fungi, actinomycetes, and macrofauna; usually around 10% of SOM), and humus which is the largest soil C pool and is composed of biomolecules and humic substances (Kalbitz et al. 2000). Biomolecules include organic acids, amino acids, proteins, sugars, polysaccharides and lignin. Humic substances are operationally defined as fulvic acids, humic acids and humin. Humus is formed through the decay of SOM driven by microbial oxidation of organic carbon compounds by heterotrophic organisms. One product of this process is CO_2 gas which is respired by heterotrophic organisms and through the metabolism of organic matter. This forms the heterotrophic component of soil respiration which will be discussed in more detail in section 1.1.4. Of the partially decomposed SOM that remains, a fraction of it is polymerized resulting in the production of complex humic substances. Another fraction undergoes intermolecular aggregation to form molecular aggregates. DOC is an operational definition based on size. Often DOC refers to carbon molecules in solution that are less than 0.45 μm in size but sometimes, as in this study, DOC includes all carbon that passes through a combusted Whatman GF/F glass fiber filter (0.7 μm).

Controls on both the production and solubility of DOC are complex and research is ongoing; however, to better understand the context for the current study the principal controls can be broadly categorized as: (a) organic controls (amount of litter and organic material, substrate quality and decomposer community); (b) chemical and physical controls (pH, ionic strength, concentration of dissolved cations/anions, and sorption/desorption processes); and (c) environmental controls (temperature, precipitation, snow pack duration and melt, soil water fluxes and soil moisture).

a) Organic controls

Although the release of DOC has been studied extensively, it is not clear whether DOC originates primarily from recent litter or from further degradation of stable organic matter. Both have been shown to constitute significant sources of DOC, but the relative magnitude of these contributions remains poorly understood (Kalbitz et al. 2000). Both the substrate quality and the decomposer community play a role in determining the rate at which DOC is produced; however, both of these factors vary greatly from site to site. In general, sites with higher carbon input (litter) and a more active decomposer community result in higher rates of DOC production, subject to variability in the environmental factors discussed below.

b) Chemical & physical controls

It is generally assumed that sorption of DOC to mineral surfaces is more important than decomposition in reducing the concentration of DOC in soils (Kalbitz et al. 2000). Concentrations and fluxes of DOC have been observed to decrease with soil depth (Michalzik & Matzner 1999), suggesting that increasing contact with mineral soils effectively removes DOC from solution. Mechanisms that may contribute to the removal/addition of DOC include anion exchange, ligand exchange surface complexation, cation bridging, hydrogen bonding, van der Waals forces and physical adsorption. Both the abundance of clay minerals and the oxide/hydroxide content of soils correlate with increased DOC adsorption, and the surface area of minerals is an important factor controlling the adsorption capacity of the soil (Gu et al. 1995, Mayer 1994a and b). Adsorption results in fractionation of DOC as hydrophobic substances are preferentially sorbed (Jardine et al. 1989, Kaiser and Zech 1998), leaving the solution enriched in the hydrophilic fraction. This process results in preferential mobilization and transport of the hydrophilic fraction of DOC compounds (Guo and Chorover 2003). Other properties of organic matter (OM) are also known to have an active role in controlling sorption of OM to metal oxides, including molecular weight, organic N, acid functional groups and aromatic moieties (Gu et al. 1995, Chorover and Amistadi 2001). In most soils the number of available sites is not infinite and increased sorption limits the number of sites available (Vance and David 1992, Moore et al. 1992). Anions in solution such as phosphate and sulfate may also compete with DOC for sorption sites (Tipping 1981, Jardine et al. 1989, Vance and David 1992, Gu et al. 1995), but in general DOC has a greater affinity for sorption than sulfate (Kaiser and Zech 1997). Prevalence of major cations appears to reduce DOC leaching from soils and increase DOC retention (Tipping and Woof 1990, 1991, Greenland 1971). However, in general the effect of ionic strength on DOC mobilization is very complex and competing processes may result in little overall effect.

The relationship between soil pH and DOC sorption is complex and studies have yielded a range of results. This is due to the fact that different soils have maximum adsorption capacities at different pH values. Furthermore, pH can affect different controls on DOC release because the solubility of DOC depends on the charge density which in turn depends on the pKa value and the pH of the solution (Tipping and Hurley 1998, Tipping and Woof 1990). Although in the lab increased pH generally corresponds with DOC release, under the pH range of natural waters the effect of pH is minimal (Kalbitz et al. 2000).

c) Environmental controls

Numerous field studies have shown seasonal variability in DOC concentrations and fluxes. While temperature is an important factor in regulating microbial production of DOC (Christ and David 1996), no clear and consistent patterns have been observed between DOC flux and temperature in the field. This is likely because hydrologic conditions, litterfall and litter quantity and various soil properties exert stronger control over DOC mobilization (Kalbitz et al. 2000, Chow et al. 2006).

Soil moisture has been observed to exert a strong control over DOC flux, not least because dissolved fluxes inherently require moisture flux as a means of mobilization. Increases in DOC flux with wetting following dry periods have been observed in both field and laboratory studies (McDowell & Wood 1984, Zabowski and Ugolini 1990, Haynes and Swift 1991, Chittleborough et al. 1992, Lundquist et al. 1999, Tipping et al. 1999). Lundquist et al. (1999) provide three explanations for this phenomenon: reduced microbial use of DOC during dry periods; enhanced turnover of microbial biomass and condensation of microbial products by re-wetting; and disruption of soil structure freeing previously sequestered DOC. Field studies show that duration of dryness and water fluxes are both positively correlated with the amount of DOC released during soil leaching after a dry period (Chittleborough et al. 1992, Tipping et al. 1999). On the other end of the soil moisture spectrum, saturation and the development of anaerobic conditions also appear to correlate positively with increased DOC release (Mulholland et al. 1990, Sedell and Dahm 1990).

Although re-wetting of dry soils and water-logging both tend to produce higher DOC fluxes, increased moisture flux has been observed to have a dilution effect. Storms are observed to flush DOC adsorbed on aggregates and from micropores, contributing to higher fluxes and increased DOC concentrations in storm runoff at the beginning of storm events (Jardine et al. 1990, Chittleborough et al. 1992). For most storm events, after the initial pulse DOC concentrations typically decrease (Jardine et al. 1990, Easthouse et al. 1992). It has also been observed that longer contact times between soils and soil solutions strongly controls the amount of DOC in solution (McDowell and Wood 1984, Michalzik and Matzner 1999). These observations have been corroborated in the lab where DOC adsorption is more pronounced at lower pore water velocity (Weigand and Totsche 1998).

Similar to storm events, DOC fluxes spike with the first pulse of spring snowmelt moving through the soil, and concentrations decline rapidly as snowmelt progresses (Yavitt and Fahey 1985, Boyer et al. 1997). This can be explained as DOC that accumulated under the snowpack through the winter being flushed from the soils with the first pulse of moisture, or alternately as new DOC produced as microorganisms take advantage of newly available moisture (Yavitt and Fahey 1985). A third explanation for increased DOC at the onset of snowmelt is that freeze-thaw cycles break up soil structure freeing previously stabilized DOC (Kalbitz 2000, Yu et al. 2011). Haei et al. (2010) observed that more severe winters (longer, colder winter seasons and prolonged soil frost) increased DOC concentrations in stream water during the subsequent snowmelt.

Few studies have focused on quantifying the relative magnitudes of DOC and DIC fluxes from soils; however, Kindler et al. (2011) showed that the relative amounts of total dissolved soil carbon flux that are contributed by DIC and DOC, respectively, vary both in space and time. DIC is quantified as the sum of all carbonate species in solution, and may be produced through the dissolution of CO_2 gas (Eq. 1.1.a) or through the dissolution of carbonate rock (Eq. 1.1.b):

$$CO_{2\,(g)} + H_2O = H_2CO_3 \qquad \text{Equation 1.1.a}$$

$$H_2CO_3 + CaCO_3 = 2HCO_3^- + Ca^{+2} \qquad \text{Equation 1.1.b}$$

Total system DIC, i.e. [DIC], is described by the following equation:

$$[DIC] = \left[CO_{2\,(aq)}\right] + [H_2CO_3^0] + [HCO_3^-] + [CO_3^{2-}] \qquad \text{Equation 1.1.c}$$

The speciation of Eq. 1.1.c is determined by soil solution pH and pCO_2. When soil pH is low (pH < 6, depending on temperature and pressure conditions), H_2CO_3 is the dominant species in solution, while at moderate pH ($6 < pH < 10$) HCO_3^- will predominate, and at high pH (pH > 10) CO_3^{2-} is most abundant. The concentrations of species in solution can be calculated based on known chemical relationships, assuming that the system is at equilibrium.

Similar to organic C fluxes, inorganic C fluxes are controlled by physical and environmental factors. While soil temperature, pH and pCO_2 directly control the concentration of DIC in solution, other factors affect DIC flux as well including moisture flux, bedrock/soil mineralogy, and soil texture among others. Parfitt et al. (1997) found that DIC fluxes were greater from sites under agricultural cultivation than from adjacent forested sites exposed to otherwise comparable conditions. Vegetation type and landscape position also affect DIC flux (Kindler et al. 2011). Overall, the mechanisms controlling the concentrations of DIC and DOC in soil solution as well as the rates at which C is removed from the soil system via dissolved fluxes are complex. The potential for competing processes to have a compensatory effect when combined is relatively high.

1.1.4 Soil Carbon Loss: Gaseous Carbon Flux

While few studies have looked at the relationship between fluxes of dissolved and gaseous carbon lost from soils, Brooks et al. (1999) observed a positive linear relationship between DOC leaching and CO_2 efflux. In general, gaseous C fluxes from soils exceed dissolved fluxes in magnitude. Soil C efflux is subject to both temporal and spatial variability and the controls on the rate by which carbon is lost from soils as CO_2 are both numerous and complex. The most important controls on soil CO_2 efflux are temperature, moisture availability, substrate availability, oxygen and nitrogen availability, soil texture, soil pH and the interactions between some or all of the above (Luo & Zhou 2006). Furthermore, CO_2 efflux exhibits distinct seasonal trends that are not simply a response to seasonal climatic variability, but rather due to distinct contributors to soil respiration: plants (autotrophs) and microbes (heterotrophs). During the growing season, comparatively high fluxes are the combined product of both heterotrophic respiration and autotrophic respiration, while during the dormant season when plants are relatively inactive soil respiration is primarily a product of heterotrophic activity. Respiration in plants, animals and microbes is the process by which sugars are converted to energy through the oxidation of organic matter (usually glucose or other carbohydrates) and can be described generically as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy \qquad \text{Equation 1.2.a}$$

Thus both autotrophic and heterotrophic respiration produce CO_2 as a product, which is released into the soil and then diffuses back to the atmosphere, or can be dissolved in soil pore water. The combined product of both heterotrophic and autotrophic respiration during the growing season generally results in significantly greater carbon losses from soils during summer. Due to this mechanistic difference between summer and winter soil gas flux, few researchers have directly compared winter and growing season fluxes.

Ecosystem productivity during the growing season has long been linked to temperature. Similarly, soil respiration is also highly sensitive to temperature, as both both microbial activity and plant productivity increase rapidly in response to increasing temperature. The relationship is often described by an exponential function referred to as an Arrhenius equation (Luo and Zhou 2006):

$$\mathrm{R} = de^{\left(-\frac{E}{RT}\right)} \qquad \text{Equation 1.2.b}$$

where R is respiration, d is a constant, E is activation energy, *R* is the ideal gas constant and T is temperature in degrees Kelvin. A common metric of quantifying the sensitivity of respiratory responses to temperature is Q_{10}, a quotient describing the response of respiration to a given change in temperature (10 ˚C), as defined by the following equation:

$$Q_{10} = \frac{R_{T+10}}{R_T} \qquad \text{Equation 1.2.c}$$

where R_T and R_{T+10} are the respiration rates at the reference temperature T and at T+10 ˚C, respectively. This method has been widely used; however, under water-stressed conditions or when there is insufficient C-substrate available temperature is no longer a strong predictor of soil C efflux (e.g. Wildung et al. 1975, Davidson et al. 1998, Curiel-Yuste et al. 2003).

Since soil temperature and soil moisture are often interdependent, under high temperature conditions, soil moisture often becomes limiting (Curiel-Yuste et al. 2003). Several recent studies have demonstrated that under dry conditions soil respiration responds rapidly to pulses of moisture produced by intermittent precipitation events (Huxman et al. 2004a, Inglima et al. 2009). Moisture limitation of soil respiration is particularly common in arid environments, but can also occur under sub-zero temperature conditions where the amount of liquid water available is a function of soil temperature. In addition to being a limiting factor under dry conditions, soil moisture levels can also limit CO_2 efflux under saturated conditions by reducing oxygen availability (Skopp et al. 1990). Oxygen is the principal reactant for the reaction by which CO_2 is produced in soils. Root respiration is negligible in the absence of oxygen; optimal oxygen conditions vary with species but are generally between 5 and 16 % (Nobel and Palta 1989). The microbial response to oxygen limitation depends on the microbial community present in the soil. Obligate aerobes require oxygen and a sharp decrease in respiration occurs when O_2 becomes limited (Luo and Zhou 2006). Facultative anaerobes can function well both with and without oxygen, while obligate anaerobes only thrive under anoxic conditions.

Therefore the response of soil microbes to oxygen limitation is determined by the types of microbes present in the soil microbial community.

Soil texture can play an important role in moderating soil respiration because it regulates porosity and thereby the water holding capacity of the soil, as well as water and gas movement within the soil (Skopp et al. 1990, Castellano et al. 2011). Dilustro et al. (2005) observed significant correlations between soil moisture and soil respiration from sandy soils when soil water content was above the wilting point, but during warm dry periods respiration from the sandy soils decreased while respiration from clay-rich soils appeared to be buffered against dry conditions. In another study of the effect of soil texture on CO_2 efflux, sandy soils were observed to respond rapidly to re-wetting while fine textured soils responded at about half the rate, probably because CO_2 could diffuse more easily through the large pores of the sandy soil (Bouma and Bryla 2000).

Nitrogen content of the soil has been shown to correlate with high rates of soil respiration due to the critical role of nitrogen in plant productivity (Burton et al. 1998). Generally soil CO_2 production appears to increase with increasing pH when $pH < 7$, and decrease with increasing pH when $pH > 7$ (Kowalenko and Ivarson 1978). However, the pH range of natural soils is not usually extreme enough to limit microbial activity, so pH only rarely has a significant effect on respiration rates. Although many factors have been shown to affect rates of soil CO_2 efflux, in the majority of field cases the combined effect of moisture and temperature explains much of the variability in CO_2 efflux.

Prior to the 1990s very little work was done on winter soil respiration rates in snow covered systems, presumably because at low temperatures microbial activity is relatively low. However, while winter fluxes are indeed generally lower than growing season fluxes, they still represent a significant C loss from soils. Brooks et al. (1996) showed that microbial activity beneath seasonal snowpacks is not only significant, but also contributes to moderating nitrogen cycling before plants become active. Soil microorganisms are thought to be active at temperatures as low as -5 to -7 ˚C (Brooks et al. 2004) and further work on winter soil C efflux has shown that the development of seasonal snow cover exerts a strong control on the magnitude of C fluxes. Years with reduced snowpack are accompanied by significantly lower soil C efflux, which has been attributed to the insulating effect of snow and to the development of a unique microbial community that exhibits high rates of substrate utilization at cold temperatures beneath snow (Monson et al. 2006). Other studies have shown that while subnivian microbial communities may be highly productive, C-limitation may limit rates of winter soil respiration (Brooks et al. 2005). Additional process level controls on winter CO_2 efflux include: freeze-thaw cycles, sub-nivean soil temperature and soil moisture availability (Liptzin et al. 2009). Oquist et al. (2009) showed that microbial responses to temperature variation at sub-zero temperatures are in fact closely linked to moisture deficiency caused by freezing of soil water, and that the amount of unfrozen water present in frozen soils is dependent on the quality of organic matter in the soil. Harrysson-Drotz et al. (2009) further demonstrated that soil texture and physical properties also control the proportion of liquid water present at sub-zero temperatures. They found that both matric and osmotic potential contributed to controlling the liquid water content of the soils, and they suggested that the larger the pores in which unfrozen water is found, the more microbial activity can be sustained. It appears that as soils freeze, the environmental factor predominantly controlling heterotrophic CO_2 production in sub-zero soils may change. Not only the amount but also the composition of SOM affects the pore size distribution and thus the unfrozen water content, and under these conditions microbes appear to respond primarily to water availability. Due to the complexity of this system, winter climate plays a significant role in regulating soil C efflux.

1.1.5 The Role of Climate in the Soil Carbon Cycle

Both carbon uptake and carbon loss are highly sensitive to climate, and climate change can also be directly impacted through feedbacks with the C-cycle (Field 2007, Luo 20007). The different ways in which C-uptake and C-loss respond to temperature and moisture availability dictate how C balance is affected (Anderson-Teixeira et al. 2011). Atkin & Macherel (2009) suggest that plant respiration responds negatively to water stress; but C-uptake via GPP is known to be highly responsive to moisture availability and under drought conditions plants have decreased ability to take up carbon (Huxman et al. 2004b, Jenerette et al. 2008, Adams et al. 2009, Inglima et al. 2009). The timing of precipitation is also important in controlling carbon dynamics. For example, Shen et al. (2008) found that increases in the magnitude of individual precipitation events resulted in greater soil C losses. They further observed that increases in annual precipitation and decreases in summer precipitation resulted in increased C-uptake in an arid ecosystem. Similarly, Brooks & Litvak (in prep.) show that while annual precipitation correlates with increased C-uptake (R^2 = 0.50), winter precipitation alone is the primary control on this process (R^2=0.94), while summer precipitation shows no significant relationship with plant activity. Tree ring studies corroborate the relationship between cool-season precipitation and tree growth in Southwestern North America (St George et al. 2010).

Climate models predict warmer and dryer conditions across western North America in the future. Furthermore, changes in the amount and timing of snowpack development across the western mountains of North America (Mote et al. 2005, Harpold et al. in review) may have significant implications not only for C-uptake as has been observed by Brooks and Litvak (in prep.) but also for the amount of carbon lost from soils. Shifting the balance between C-uptake and C-loss has the potential to drastically alter NEE (Ciais et al. 2005, Piao et al. 2008, Piao et al. 2009), and any net change in carbon balance acts as a feedback to climate change (Field et al. 2007).

Looking ahead, modeling efforts to better predict climate rely heavily on a large number of complicated and often poorly understood processes (Luo 2007, Hayes et al. 2012). To better constrain how soil carbon losses respond to seasonal and inter-annual climate variability, here I examine how the relative magnitudes of DOC and CO_2 fluxes compare over two years within subalpine mixed conifer forests in Southern Arizona and

Northern New Mexico. Furthermore, I investigate how soils and vegetation type moderate the responses of these systems to climatic variability.

1.2. Study Site Description

Data were collected at two subalpine sites in Southern Arizona and Northern New Mexico (Figure 1). These sites were selected because both are characterized by subalpine mixed-conifer forests with distinctly bimodal precipitation and soil moisture regimes. However, they differ in that the Valles Caldera, located in the Jemez Mountains of Northern New Mexico, experiences seasonal snowpack development during winter months that may vary in duration, whereas at Marshall Gulch in the Santa Catalina Mountains of Southern Arizona snowpack development is ephemeral and varies from year to year. Although difference in lithology may produce confounding variation, compiling data from both of these sites provides a climate gradient from which I can draw conclusions on how predicted shifts towards a warmer and dryer climate across the Southwest in the future may impact soil carbon flux.

Marshall Gulch is located at the crest of the Santa Catalina Mountains just north of Tucson in Southern Arizona. Marshall Gulch is a first order basin of 1.6 km^2. Located at 2370m elevation, this area is dominated by mixed conifer forest: Douglas-fir, white fir, ponderosa pine, and bigtooth maple are the predominant species of trees while Gamble oak, buckbrush and catclaw acacia dominate the understory. Marshall Gulch drains to a perennial stream with peak discharge during the spring snowmelt and a secondary peak in response to monsoon rains. The mean annual discharge of the stream during a four year study period (2008 to 2011) ranges from 3.3 l/s in 2011 to 19.8 l/s 2010. The basin is characterized by a mesic soil temperature regime with approximately 10 ˚C mean annual air temperature, and an Ustic soil moisture regime. Mean annual precipitation is approximately 900mm.

Within the Marshall Gulch basin two sub-sites with distinct parent materials and soil types were identified. Both sub-sites are contained within zero order basins and experience the same climatic conditions. Additionally, both zero order basins drain to the Northeast and have predominantly Northwest, North, Northeast, East and Southeast aspects. The slopes of both basins are between 22 and 27 degrees and elevation and the vegetation species assemblages are similar (Table 1). However, the two sub-sites differ in that in that one is underlain by the Wilderness Granite, an Eocene muscovite-garnet leucogranite that weathers to produce a coarse-grained soil, while the other is underlain by the Pioneer Schist unit, a Middle-Proterozoic metamorphic unit that weathers into a finer-grained soil (Force 1997). While both of these geologies tend to have thick saprolites, varying thicknesses of regolith are developed, depending on parent material and relief (Guardiola-Claramonte 2008).

The granite zero-order basin has an area of 5.6 hectares with average slopes of 23 degrees. Mean soil depths range from 0.6m to 0.9m. Organic matter in the soil profile is concentrated in the top 7cm of the soil profile. Within the O/A soil horizon (0-10 cm depth), the granite-derived soils have on average 8% clay and 9.42 ± 0.57 % soil organic matter (Table 2). CEC in this layer is 40meq/100 g soil or 5.48 meq/100g clay (Guradiola-Claramonte 2008, Table 2).

The schist sub-site is comprised of a 4.9 hectare zero-order basin with average slopes of 25 degrees. There is an intermittent seep that flows during the snowmelt and monsoon seasons. Soil depths are generally deeper than the granite site, ranging from 0.7m to 1.2m, and the soils are mostly sandy loams with 10% clay fraction and 10.09 ± 0.99 % soil organic matter in the O/A horizon (0-10 cm depth, Table 2). The average cation exchange capacity (CEC) of soil in this layer is 195.6 meq/100g of soil, or 20.8 meq/100g of Clay (Table 2), and CEC decreases with increasing soil depth; these values of CEC typically correspond to illite, but could also correspond to weathered kaolinite (Guardiola-Claramonte 2008). In general, the schist bedrock tends to produce both deeper and more developed soils with finer textures and higher CEC than the soils produced from granite bedrock. Furthermore, the schist-derived soil has been found to have lower hydraulic conductivity (0.76 mm/s) compared with the granite-derived soil (1.31 mm/s), and the mean water residence time as well as the hydrologic storage capacity for the schist basin are both significantly higher than for the granite basin (Heidbüchel et al. in prep.). The distinct soils at these two sub-sites along with their otherwise very similar features make these sites ideal for comparing the effects of soil physical properties on the rates at which carbon is lost from these soils as DOC and CO_2.

The Valles Caldera field site, located within the Jemez River Basin in Northern New Mexico, in addition to being further north is also at 3030m elevation, slightly higher than Marshall Gulch. This area receives approximately 700mm of average annual precipitation of which typically around 40% occurs as snowfall during winter and the remainder as summer monsoon rains. The mean annual air temperature is 3˚C. Like Marshall Gulch, the site at the Valles Caldera is dominated by a mixed conifer forest; however, due to the higher elevation of this site the species assemblage is primarily white fir, subalpine fir and Engleman’s spruce, with some Douglas fir on south-facing aspects. This area has a history of logging, and the areas included in this study were last logged in 1963. The forests are re-established but are still in the process of regeneration. Among the regenerated forest stands, montane meadows composed of a variety of grasses and forbes predominate. Some of the regenerated stands are undergoing varying degrees of attack by spruce budworm (*Chroristoneura occidental*). The larvae of this beetle devour the new spring growth of Douglas fir and most spruce and fir species, and over time can deplete the trees’ energy reserves, resulting in severe defoliation, decreased growth, top-killing and in some cases mortality (Fellin and Dewey, 1982).

To address the effects of insect attack on soil respiration I selected sub-sites within the Valles Caldera site, one of which was comprised of a large stand of forest that has been strongly impacted by spruce budworm and is co-located near an eddy-covariance flux tower and has neutral slope and aspect. My second sub-site was a healthy stand of forest. I included a third sub-site characterized by meadow/grassland in order to better represent respiration from the broader ecosystem. Preliminary data were collected from a range of healthy forest and meadow sites during 2010; however, these sites were discontinued at the end of the year. Throughout the snowmelt and monsoon seasons of 2011 I continued sampling the impacted site and additionally sampled a healthy forest sub-site and a meadow sub-site with southwest aspects as well as comparable sites with northeast aspects. Both the southwest-facing meadow and the northeast-facing forest were co-located with soil pits instrumented with capillary wick and Prenart suction cup soil solution samplers, and soil moisture, matric potential, electrical conductivity and temperature probes.

1.3 Thesis Format

The format of this thesis is outlined by the University of Arizona Graduate College’s *Manual for Theses and Dissertations* and is therefore subject to repetition of information. The first chapter describes the context and relevance of this work. The second chapter describes the present study and briefly summarizes the findings described in Appendix A.

Appendix A is a scientific manuscript on the role of hydrologic and climatic variability in regulating soil carbon flux and is planned for submission to an as yet undecided venue. The manuscript repeats the introduction, conclusions and implications presented in chapters 1 and 2, and further discusses the results of this research. Appendices B-F describe additional research and data that were collected as part of this study.

1. PRESENT STUDY

Please note: the context, methods, results and conclusions of this study are presented in a manuscript for publication entitled “The Role of Hydrologic Variability in Controlling Soil Carbon Flux in Two Semi-Arid Montane Sites,” included with this document as Appendix A. The following section summarizes the methods and findings of this paper.

2.1 Present Study

The principal goals of this study were to determine the relative magnitudes of gaseous and dissolved fluxes of carbon from near surface soils and to quantify the primary controls on these fluxes. While little work has been focused on the relationship between dissolved and gaseous carbon losses from soils, Brooks et al. (1999) observed a positive linear relationship between leached DOC fluxes and CO_2 efflux from soils in the Rocky Mountains of Colorado. My first objective is to see if this relationship is also observed at two additional sites in Arizona and New Mexico. From previous work on soil carbon fluxes, it is reasonable to expect that environmental factors will exert a strong control on both dissolved and gaseous soil C fluxes. Because my sites are located in the semi-arid southwest, I hypothesize that water availability will be an important control on both fluxes. My second objective is to quantify the role of inter-annual and seasonal climate in driving soil carbon flux and my third objective is to address the role of soil texture in moderating the response of soil C fluxes to climate variability.

To address these questions, I measured dissolved and gaseous C fluxes in soils at two subalpine sites in Southern Arizona and Northern New Mexico. These sites were selected because both are characterized by subalpine mixed-conifer forests with distinctly bimodal precipitation and soil moisture regimes. However, they differ in that the Valles Caldera, located in the Jemez Mountains of Northern New Mexico, experiences seasonal snowpack development during winter months that may vary in duration, whereas at Marshall Gulch in the Santa Catalina Mountains of Southern Arizona snowpack development is ephemeral and varies significantly in that some years a snowpack develops comparable to that of the site in New Mexico, while other years the snowpack fails to develop. Within the Marshall Gulch basin two sub-sites with distinct parent materials and soil types were identified. Both sub-sites have comparable slope, aspect and vegetation species assemblages, are at approximately the same elevation (Table 1), and are subjected to the same climatic conditions. The two sub-sites differ in that one is underlain by a granitic parent material that weathers to produce a coarse-grained soil, while the other is underlain by schist that weathers into a finer-grained soil (Guardiola-Claramonte 2008). Compiling data from the sites in both Arizona and New Mexico sites allows me to compare the distinct responses of sites along a climate gradient to interannual climate variability. The soil texture comparison facilitates an analysis of how the soils themselves can moderate the response of soil carbon loss to climate variability.

Samples were collected through 2010 and 2011 before, during and after the spring snowmelt and summer monsoon from a minimum of three representative plots at each site. DOC flux was quantified by installing three mixed bed ion exchange resin traps at each plot at 10cm depth prior to the onset of each precipitation season to capture DOC leached from surface soils (O/A soil horizon). The traps were constructed based on the design used by Brooks et al. (1999) and consisted of ~20 cubic centimeters of mixed anion and cation exchange resins (J.T. Baker, IONAC NM-60 H^+/OH^- Form, 16-50 Mesh) sewn into acid-washed nylon bags and secured within 1.5 cm-diameter PVC pipe open at the top and bottom to collect leachate from overlying soils. The traps were installed by removing an intact block of soil, installing the trap and then replacing the soil. Traps were recovered at the end of the season and processed in the laboratory where they were air dried and extracted with 2M KCl (1:5, weight:volume). Extracts were filtered through Whatman 1 paper filters and stored at 4°C until processing.

Fluxes of DIC were estimated based soil pH and a range of soil pCO_2 values. The mean pH of the schist and granite soils were 5.9 and 6.6, respectively. At this pH range, DIC concentration can be approximated as the summed concentrations of carbonic acid and bicarbonate:

$$[DIC] = [H_2CO_3^0] + [HCO_3^-] \qquad \text{Equation 2.1.a}$$

Assuming that concentration is approximately equal to activity, $[H_2CO_3^0]$ and $[HCO_3^-]$ can be calculated according to the following equations:

$$[H_2CO_3^0] = \frac{K_1 K_{\text{CO}2} pCO_2}{[H^+]} \qquad \text{Equation 2.1.b}$$

$$[HCO_3^-] = \frac{[H^+]\,[H_2CO_3^0]}{K_1} \qquad \text{Equation 2.1.c}$$

Where $[H_2CO_3^0]$, $[HCO_3^-]$and $[H^+]$ are concentrations, K_1 and $K_{\mathrm{CO}_2}$are equilibrium constants corrected for soil temperature and pressure conditions, and pCO_2 is the partial pressure of CO_2 within the soil. Measurements of soil pCO_2 were not available so pCO_2 values were estimated based on CO_2 concentration measurements from the base of the snowpack and compared with values of soil pCO_2 cited in the literature. In order to convert DIC concentration into seasonal and annual fluxes I multiplied the concentration of DIC in soil solution by the cumulative seasonal and annual precipitation. Cumulative precipitation is probably an overestimate of the total moisture flux for these systems, given that some quantity of precipitation is lost to evapotranspiration/sublimation, runoff, etc. However, for the purposes of this study, calculating a more rigorous water balance was unfeasible. Furthermore, given the uncertainty in estimated soil pCO_2 values, the uncertainty in moisture flux is probably negligible.

At each plot five CO_2 flux measurements were taken in situ before, during and after each precipitation season using a portable infrared gas analyzer (IRGA, PP Systems, EM-4). During snow-free periods a chamber attachment was used with the IRGA. During snow-covered periods CO_2 flux was estimated by measuring the concentration of CO_2 at ten centimeter intervals through the snowpack (Figure 2). Fluxes were calculated from the vertical concentration profile using a steady state diffusion model based on Fick's Law:

$$J_{CO_2} = D_{CO_2}\left(\frac{d[C_{CO_2}]}{dz}\right)f \qquad \text{Equation 2.1.d}$$

Where J_{CO_2} is the flux, D_{CO_2} is a diffusion coefficient, z is the depth of the snowpack, and f is the porosity of the snowpack. The diffusion coefficient D_{CO_2} was assumed to be 0.139 for CO_2 gas and is the same as that used by Brooks et al. (1996, 1999) and Sommerfeld et al. (1993). Porosity was calculated as the inverse of snowpack density. Molar gas volumes were corrected for local temperature and pressure conditions.

I used precipitation and air temperature data collected by RAINEW 111 Tipping Bucket Wired Rain Gauges and a HOBO U20-001-01 probe and data logger at Marshall Gulch, and snow depth and duration data from a meteorological station located ~3 km away at comparable elevation. At the Valles Caldera site I used precipitation, air temperature and snow depth and duration data from the meteorological station adjacent to the site.

I collected data through the snowmelt and monsoon seasons of 2010 and 2011. Dissolved fluxes were sampled corresponding with each precipitation season. Gaseous fluxes were sampled throughout both the snowmelt and monsoon seasons. However, gaseous fluxes were analyzed based on seasons defined by growing season to differentiate between times when soil respiration is generated mainly by heterotrophic activity and when it is the combined result of both heterotrophic and autotrophic activity. Monson et al. (2005) showed through eddy covariance methods that plants respond rapidly as soon as liquid water becomes available during snowmelt, suggesting that as soon as melting begins, plants become active and soil CO_2 efflux switches from being primarily microbial respiration to a combination of microbial and plant root respiration.

For my analysis of gaseous flux, I defined seasons as ‘winter’ during the snow accumulation period, and ‘growing season’ from peak snow water equivalent (SWE) to beginning of next accumulation period.

Samples were collected using a nested sampling design. At each site three to five 1 m^2 plots were selected and at each plot three DOC flux samples and five CO_2 flux samples were collected. This allowed me to evaluate between-plot and within-plot variability for each site each time samples were collected. All statistical analyses were performed in JMP 9 software (SAS System, 2007). I used the Wilcoxan/Kruskal-Wallis rank sums test for non-parametric data to determine if mean dissolved and gaseous fluxes and mean soil moisture differed between seasons, years and sites. Each time samples were collected a mean and standard error were calculated for each plot. Simple linear regressions were used to determine the relationships between plot means for gas flux and soil temperature and moisture by season. Soil moisture and bulk soil C were included in a multiple linear regression model to predict gas flux.

2.2 Results and Implications

2.2.1 Context for Research

As atmospheric CO_2 concentrations continue to rise, the importance of carbon sequestration has garnered increasing interest. Carbon is removed from the atmosphere via photosynthesis, endowing forests with the capacity to take up significant amounts of carbon. Most terrestrial carbon sequestration at mid-latitudes in the northern hemisphere occurs in montane forest ecosystems (Schimel et al, 2002). While both spatially and temporally variable, net C-uptake in montane forests is sensitive to climatic variability. Drought limits forest productivity, while forests have been observed to respond positively to increased precipitation, particularly winter precipitation (Brooks & Litvak, in prep.). Carbon uptake via photosynthesis has been widely studied and eddy covariance methods have provided a quantitative approach to estimating gross primary productivity and net ecosystem exchange. Soils are known to be significant carbon sinks and they form the largest terrestrial carbon pool, so constraining the amount of carbon lost from soils is critical to understanding carbon sequestration dynamics. Carbon is stabilized in soils via chemical and physical mechanisms. Once part of the soil carbon pool the residence time of carbon may vary from days to thousands of years (Trumbore 1993, Gaudinski et al. 2000). However, carbon can also be lost from soils via two pathways: DOC leaching and CO_2 efflux. DOC fluxes from surface soils can vary in magnitude from 5 g Cm^{-2} yr^{-1} to 84 g Cm^{-2} yr^{-1} (Neff and Asner, 2001), while soil respiration can account for 60-80% of total ecosystem respiration (Law et al. 1999, Janssens et al. 2001, Milyukova et al. 2002). As much as half of the C fixed during the growing season can be lost during the winter in montane, seasonally snow-covered systems (Monson et al. 2002, Hubbard et al. 2005). Understanding carbon losses from montane forest ecosystems is thus critical for constraining the carbon balance for these systems.

2.2.2 Seasonal and Inter-annual Climate

The two years over which this study was conducted vary significantly with respect to total annual precipitation and the proportion of annual precipitation that occurred during winter as snow. Cumulative annual precipitation at Marshall Gulch during 2010 was 813 mm, of which 315 mm fell as snow during the winter; the remaining 498 mm fell as summer rain (Figure 3). During 2011, the total precipitation at this site was almost half that of the previous year (461mm), with only 52mm falling during winter as snow and rain, and the remaining 409 mm falling as summer rain. During the winter of 2010 the snow cover was consistent and lasted from 31 November 2009 through 18 April 2010 (141 days). During the winter of 2011 no significant snowpack developed; infrequent storm events produced an ephemeral snowpack that lasted from 29 December 2010 through 3 March 2011 (64 days, Figure 3).

Cumulative annual precipitation at Valles Caldera during 2010 was 658 mm, of which 293 mm fell as snow during the winter and 365 mm fell as summer rain. The site remained snow covered from 7 December 2009-28 April 2010 (143 days). During 2011, the cumulative annual precipitation at this site was also much lower than in 2010 (546 mm). Winter precipitation was 226 mm, and the site remained snow-covered for 134 days from 16 December 2010-28 March 2011. Summer precipitation in 2011 was 320 mm.

2.2.3 Dissolved Fluxes

DOC C fluxes varied from 3.18 ± 0.20 g C m^{-2} y^{-1} to 10.85 ± 2.46 g C m^{-2} y^{-1}. These values of DOC flux are low but well within the range of values reported in the literature which range from 2-84 g C m^{-2} yr^{-1} (Yavitt and Fahey 1986, Moore 1989, Qualls et al. 1991, Curry et al. 1996, Brooks et al. 1999, Michaelzik and Matzner 1999, Kindler et al 2011). They compare well with fluxes reported from similar ecosystem types: 10.6 g C m^{-2} y^{-1} at a lodgepole pine forest near Medicine Bow, WY (Yavitt and Fahey, 1986), and 6.5 g C m^{-2} y^{-1} at European spruce forests (Kindler et al 2011). In general, mean fluxes were higher in summer (4.30 ± 0.28 g C m^{-2}) than in winter (3.45 ± 0.16 g C m^{-2}, Figure 4). There was no significant difference between mean DOC fluxes during 2010 and 2011 despite dramatic inter-annual variability in precipitation quantity. Furthermore, I did not observe a significant relationship between DOC flux and cumulative seasonal precipitation, suggesting that the system is limited by C supply rather than transport.

Contrary to initial expectations based on significantly higher bulk soil C at the schist site relative to the granite (Table 1), DOC flux did not vary with soil type. However, normalizing the dissolved fluxes by bulk soil carbon showed that more carbon was lost from the granitic soil than from schist soil relative to bulk soil carbon (Figure 5). Although the schist soil had significantly higher bulk carbon content, this soil was also observed to have a larger clay fraction than the granite, a higher cation exchange capacity and a lower base saturation (Table 2), suggesting that while more carbon is present in this soil it is also more likely to be bound to mineral surfaces and/or particulate organic matter and thus protected from leaching or microbial degradation (Nelson et al. 1993). DOC fluxes did not correlate with gaseous fluxes, and relative to the magnitude and variability observed among gaseous fluxes DOC fluxes were small with low variability (Figure 6).

Due to the high degree of uncertainty in soil pCO_2, fluxes of DIC are approximate. Using pCO_2 values estimated based on mean measured CO_2 concentrations at the base of the snowpack, DIC flux at the granite site was 1.2 g C m^{-2} yr^{-1} during 2011during 2010 and 0.8 g C m^{-2} yr^{-1} during 2011. At the schist site DIC flux under these conditions was 3.2 and 1.6 g C m^{-2} yr^{-1} for 2010 and 2011, respectively. These values are almost certainly underestimating DIC flux because the partial pressure of CO_2 is likely to be higher within the soil profile than at the soil surface. To gain an idea of how much larger DIC fluxes might be I re-calculated the fluxes based on values of soil pCO_2 cited in the literature for both experimental and modeled data (Johnson et al. 1994, Jones and Mulholland 1998, Andrews and Schlesinger 2001, Karberg et al 2005), which ranged from 0.8 – 3.0 % for surface soils (from 0 – 30 cm). Based on these values, DIC flux ranged from 2.3 – 17.5 g C m^{-2} yr^{-1} at the granite site and from 4.3 – 31.7 g C m^{-2} yr^{-1} at the schist site. Given the large uncertainty in my pCO_2 estimates, it is difficult to predict the effect of DIC flux on ecosystem carbon balance; however, compared with DOC fluxes, even the low values of DIC flux significantly increase the total loss of dissolved C from soils. Published values of DIC flux from surface soils range from 2 to 48 g C m^{-2} yr^{-1}, suggesting that the values based on CO_2 concentration at the soil-snow interface are probably too low an estimate for soil pCO_2. A more precise estimate of soil pCO_2 would provide much more accurate results for DIC flux from this system.

2.2.4 Gaseous Fluxes

During winter I observed significantly higher soil CO_2 efflux from sites with continuous snow cover than sites with ephemeral snow cover (Figure 7), and the values were on the high end of the range of values observed for montane systems during the snow covered season (Brooks et al. 2005, Sommerfeld et al. 1993, McDowell et al. 2000, Suni et al. 2003). The decrease in carbon flux associated with decreased snow cover is consistent with observations by Monson et al. (2006). However, while Monson et al. (2006) observed a significant relationship between soil CO_2 efflux and subnivean soil temperature, my data showed no relationship between soil temperature and CO_2 efflux (Figure 8), consistent with other observations of winter soil CO_2 efflux and soil temperature (Sommerfeld et al. 1993, Brooks et al. 1997, Brooks et al. 2004). Rather, I found a significant, positive correlation between subnivean soil moisture and soil CO_2 efflux (R^2=0.35, $p<0.0071$, Figure 9), suggesting that rather than temperature, soil moisture is the dominant control on winter soil carbon loss at these sites. The amount of liquid water present in soils at sub-zero temperatures has been shown to vary with matric and osmotic potentials (Harrysson-Drotz et al. 2009) and with the quality and quantity of soil organic carbon (Oquist et al. 2009). In addition to controlling the liquid water content of the soil, soil carbon may also limit microbial productivity (Brooks et al. 2005). My sampling resolution was insufficient to test the effect of soil pore size; however, by including gravimetric soil moisture and bulk soil carbon in a multiple linear regression model, I was able to improve my ability to predict soil CO_2 efflux at continuously snow covered sites ($R^2=0.55$, $p<0.0062$).

During summer mean daily fluxes varied from 0.72 ± 0.12 to 5.27 ± 0.31 g $Cm^{-2}d^{-1}$. As in winter, fluxes during 2010 were significantly higher than during 2011; however, under wet conditions, fluxes were significantly higher from schist soils than from granitic soils (Figure 10). The relationship between soil temperature and mean gas flux suggests that there is an optimal range of temperature between approximately 8 and 15 °C where fluxes are high, bounded on either end by less optimal temperature conditions (Figure 11). This data suggests temperature limitation at low temperatures and water limitation at high temperatures, similar to the results of Davidson et al. (1998). I observed a strong positive relationship between gas flux and moisture, with 36% of the variance in gas flux explained by soil moisture in granitic soils and 90% explained in schist soils (Figure 12). Again, this is consistent with previous observations in moisture limited ecosystems. The difference in gas flux response to soil moisture observed at the granitic and schist soils can be related to soil texture. I observed that during 2010 under wetter conditions gravimetric soil moisture at the schist site was significantly greater than at the granite site (Figure 13), and Heidbüchel et al. (in prep.) have observed both longer residence times and higher water holding capacity for the schist soils than for the granite soils at the Marshall Gulch site. The lower clay content, large pore size and shallow soil horizons at the granite site make it susceptible to drying rapidly after precipitation events, while higher clay content, smaller pore size and deeper soil horizons of the schist soil more effectively retain water under wet conditions.

Plant productivity contributes directly to soil CO_2 efflux through root respiration, and plants in arid systems are often water-limited. In order to assess whether the difference in CO_2 efflux during summer 2010 was due to more productive vegetation at the schist site, I looked at the effect of leaf area index (LAI), a unitless index calculated from LIDAR (Light Detection And Ranging) by analyzing light reflected and refracted from the land surface that has been used successfully as a proxy for vegetation productivity in previous soil respiration studies (Reichstein et al. 2003). I used LAI calculated from the LIDAR data set collected by Pima County as part of the Regional FCD Topographic Mapping project for the Marshall Gulch sites (Sanborn 2007), and from the Jemez-Santa Catalina Critical Zone Observatory LIDAR data set for the Valles Caldera Sites (Swetnam et al. in prep.). LAI was calculated based on the method of Lim et al. (2003) as used by Richardson et al. (2009).

Mean LAI at the schist site was significantly higher than at the granite site (Table 1); however, there was no significant relationship between mean summer CO_2 efflux and LAI. Normalizing CO_2 efflux by LAI decreased the difference in CO_2 flux between the schist and granite sites but did not alter the significant patterns. The low correlation between LAI and CO_2 efflux along with higher LAI-normalized CO_2 flux from the schist site during summer 2010 suggests that while vegetation productivity may contribute to higher fluxes it cannot fully explain them, thereby indicating that heterotrophic respiration is also responsible for the higher rates of CO_2 efflux from the schist soils.

These results suggest that soil moisture limits both autotrophic and heterotrophic soil respiration.

2.2.5 Conclusions

In summary, dissolved C fluxes in these systems (both DIC and DOC) are small relative to gaseous fluxes. Gaseous fluxes both in summer and winter are principally controlled by moisture availability and are subsequently highly responsive to inter-annual climate variability. My data show that during wet years, gaseous soil C fluxes are higher than during dry years during both winter and summer. Furthermore, during wet summers the physical properties of the soils appear to modulate the response of soil respiration to climate.

In the context of ecosystem C balance and the response of montane forest systems to predicted climate change, the implications of these observations are significant. The results of this study show that decreased annual precipitation results in decreases in both dissolved inorganic and gaseous soil C fluxes. However, C-uptake and C-loss are known to respond differentially to both moisture and temperature. For example, given that increased winter precipitation leads to significantly greater C-uptake (Brooks and Litvak, in prep.) and only slightly greater gaseous C-losses, a greater proportion of annual precipitation occurring during winter would be expected to result in increased carbon uptake and only moderately increased gaseous C-loss, producing a net carbon sink. However, if annual precipitation were constant but a greater proportion of annual precipitation occurred during summer, the conditions would favor significantly increased rates of gaseous C-loss and only a weak response in C-uptake. Based on the magnitude of these responses, the seasonal partitioning of precipitation has the potential to drastically alter the capacity of temperate subalpine forest systems to act as C sinks.

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APPENDIX A: QUANITIFYING THE ROLE OF HYDROLOGIC VARIABILITY IN CONTROLLING SOIL CARBON FLUX AT TWO SEMI-ARID MONTANE SITES

"Quantifying the Role of Hydrologic Variability in Controlling Soil Carbon Flux at Two Semi-Arid Montane Sites"

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Abstract

Soil carbon is the largest terrestrial carbon pool; however, the diverse factors that contribute to soil C efflux remain poorly understood. The O/A horizon, typically rich in organic matter, is subjected to extremes in wetting and drying, and previous studies have shown that soil carbon dynamics are critically linked to moisture availability. Carbon in surface soils is mobilized via two distinct pathways: CO_2 gas efflux and leaching of dissolved organic and inorganic carbon. This study aims to quantify the role of hydrologic variability in mobilizing carbon as gaseous and dissolved fluxes from near-surface soils, and to determine the relative magnitudes of these fluxes. Samples were collected through 2010 and 2011 from subalpine sites in Southern Arizona and Northern New Mexico. Both of these sites are characterized by bimodal precipitation and soil moisture patterns associated with spring snowmelt and summer monsoon. They differ in that the site in NM is subjected to a distinct snow covered season of variable duration, while the site in AZ may have ephemeral snow cover. Dissolved organic C fluxes were low at all sites, ranging from 10.85 ± 2.46 to 3.18 ± 0.20 g C m^{-2} y^{-1}. There was no significant variability between years or between soil types. DIC flux estimates were also relatively low (from 0.8 to 31.7 g C m^{-2} y^{-1}), and included a large degree of uncertainty. In contrast, CO_2 fluxes were large (from 154 ± 8.6 to 851 8.6 ± 91 g C m^{-2} y^{-1}) and varied between sites and between years. CO_2 efflux was positively correlated with soil moisture during winter beneath continuous snowpack and during the growing season when autotrophic respiration would likely be high. Furthermore, during the 2010 growing season, fine schist soils had significantly higher CO_2 flux than coarse granitic soils. These

results suggest that soil respiration in arid montane forests is primarily controlled by available moisture and that fluxes of carbon respond to climatic variability but can be modulated by the physical properties of the soil.

Introduction

As atmospheric CO_2 concentrations continue to rise, the importance of carbon sequestration garners increasing interest (Wigley et al. 1996, Batjes 1998, Schlesinger 1999, Barford et al. 2001, Lackner 2003, Hayes et al. 2012). Significant terrestrial carbon sequestration at mid-latitudes in the northern hemisphere occurs in montane forest ecosystems (Shimmel et al, 2002). Carbon uptake via photosynthesis has been well studied and eddy covariance methods provide a quantitative approach to estimating net ecosystem exchange (NEE), and to some extent, gross primary productivity (GPP) and ecosystem respiration (R_{eco}). Whereas distinguishing between plant- and soil-respiration remains challenging, resolving their component contributions to NEE is important because they represent very different process controls and therefore, likely responses to variation in climatic drivers. Soils form the largest terrestrial carbon pool and they represent a long-term repository of soil organic carbon (SOC) inputs that derive from plant tissue senescence and partial biodegradation of photosynthate. Soils can also release SOC to the atmosphere during perturbations that make it more labile, such as during moisture infusion to dry soil (Curiel Yuste et al. 2003, Huxman et al. 2004, Inglima et al. 2009).

Soil organic carbon (SOC) is stabilized in soils via chemical, physical and biological mechanisms, and its residence time may vary from days to 1000s of years (Trumbore 1993, Torn et al. 1997, Gaudinski et al. 2000). SOC can be lost via two pathways: dissolved C leaching and CO_2 gas efflux. Reported dissolved organic carbon (DOC) fluxes from surface soils can vary in magnitude from 5 to 84 g C m^{-2} yr^{-1} (Neff and Asner, 2001), while dissolved inorganic carbon (DIC) fluxes from surface soils vary from 2 to 48 g C m^{-2} yr^{-1} (Jones and Mulholland 1998, Kindler et al. 2011). Gaseous soil C losses are generally larger than combined organic and inorganic dissolved C fluxes, ranging from 60 to 1260 g C m^{-2} yr^{-1} (Raich and Schlesinger 1992), and can account for approximately 60-80 % of total ecosystem respiration (Law et al. 1999, Janssens et al. 2001, Milyukova et al. 2002, Barron-Gafford et al. 2011). As much as half of the C fixed during the growing season can be lost during the winter in montane, seasonally snow-covered forest systems (Monson et al. 2002, Hubbard et al. 2005).

The relative magnitude of carbon pools and fluxes varies tremendously both in space and time. Variability is a function of ecosystem type (Trumbore 1993), climatic conditions (Anderson-Teixeira et al. 2011) and lithology and degree of soil weathering (Trumbore 1993, Torn et al. 1997, Chorover et al. 2004, Mikutta et al. 2009, Anderson-Teixeira et al. 2011). Temporal variability occurs on diurnal, seasonal and interannual timescales. Rates of carbon loss and uptake vary over the course of the year, with C-uptake via GPP dominating during the growing season, and C-loss via net ecosystem respiration (R_{eco}) dominating during the dormant season. Over longer timescales, NEE can fluctuate significantly, resulting in changes in storage (Anderson-Teixeira et al.

2011). Both GPP and R_{eco} have been shown to respond to climatic variables (temperature and moisture) but not necessarily in the same way or to the same extent. Over short timescales, these responses and their physiological drivers are reasonably well understood but over longer timescales they become more difficult to tease apart as R_{eco} is inherently dependent on GPP (Hogberg et al. 2001, Ryan and Law 2005, Stoy et al. 2008). Due to the distinct responses of C-uptake and C-loss to climate, the effect on carbon balance is highly complex.

Controls on both the production and solubility of DOC are complex and research is ongoing; however, primary mechanisms controlling these processes are biological (e.g., substrate availability, decomposer community), as well as chemical and physical (sorption, aggregate occlusion), and environmental (moisture, temperature). Overall, the mechanisms controlling DOC concentrations in soil solution, as well as the rates at which C is removed from the soil system via dissolved fluxes, are complex (Kalbitz et al. 2000). The potential for combined processes to have a compensatory effect is relatively high, which may in part explain why gaseous fluxes generally comprise a greater proportion of total soil C-loss.

Few studies have focused on quantifying the relative magnitudes of DOC and DIC fluxes from soils; however, Kindler et al. (2011) showed that the relative amounts of total dissolved soil carbon flux that are contributed by DIC and DOC, respectively, vary both in space and time. DIC is quantified as the sum of all carbonate species in solution, and may be produced through the dissolution of CO_2 gas or through the dissolution of carbonate rock. The speciation of DIC is determined by soil solution pH and pCO_2. When soil pH is low ($pH < 6$, depending on temperature and pressure conditions), H_2CO_3 is the dominant species in solution, while at moderate pH ($6 < pH < 10$) HCO_3^- will predominate, and at high pH ($pH > 10$) CO_3^{2-} is most abundant. The concentrations of species in solution can be calculated based on known chemical relationships, assuming that the system is at equilibrium. Similar to organic C fluxes, inorganic C fluxes are controlled by physical and environmental factors. While soil temperature, pH and pCO_2 directly control the concentration of DIC in solution, other factors affect DIC flux as well including moisture flux, bedrock/soil mineralogy, and soil texture among others. Parfitt et al. (1997) found that DIC fluxes were greater from sites under agricultural cultivation than from adjacent forested sites exposed to otherwise comparable conditions. Vegetation type and landscape position also affect DIC flux (Kindler et al. 2011). Overall, the mechanisms controlling the concentrations of DIC and DOC in soil solution as well as the rates at which C is removed from the soil system via dissolved fluxes are complex. The potential for competing processes to have a compensatory effect when combined is relatively high.

Although little work has been focused on the relationship between dissolved and gaseous carbon losses from soils, Brooks et al. (1999) observed a positive linear relationship between downward DOC effluxes and upward CO_2 efflux from soils in the Rocky Mountains of Colorado. One of my objectives was to see if this relationship held for two additional mixed conifer forested sites in Arizona and New Mexico.

Gaseous soil carbon fluxes respond strongly to changes in temperature and moisture. In arid systems, under high temperature conditions, soil moisture often becomes limiting (Curiel Yuste et al. 2003). Several recent studies have demonstrated that under dry conditions soil respiration responds rapidly to pulses of moisture produced by intermittent precipitation events (Huxman et al. 2004, Inglima et al. 2009). Plant productivity, which contributes directly to soil CO_2 efflux through root respiration, is also often water-limited in arid systems. Reichstein et al. (2003) used leaf area index (LAI) as a proxy for primary productivity to model the combined effects of plant productivity and water availability on soil respiration. Moisture limitation of soil respiration is particularly common in arid environments, but can also occur under sub-zero temperature conditions where the amount of liquid water available is a function of soil temperature. In addition to being a limiting factor under dry conditions, soil moisture can also limit CO_2 efflux under saturated conditions by reducing oxygen availability (Skopp et al. 1990).

Soil texture can play an important role in moderating soil respiration because it regulates porosity and thereby the water holding capacity of the soil, as well as water and gas movement within the soil (Skopp et al. 1990, Castellano et al. 2011). Dilustro et al. (2005) observed significant correlations between soil moisture and soil respiration in sandy soils when soil water content was high. Under warm, dry conditions respiration from the sandy soils decreased while respiration from clay-rich soils did not, suggesting that the clay soils are buffered against dry conditions. In another study on the effect of soil texture on CO_2 efflux, sandy soils were observed to respond rapidly to re-wetting while fine textured soils responded at about half the rate, possibly because CO_2 could diffuse more easily through the large pores of the sandy soil (Bouma and Bryla 2000).

Prior to the 1990s very little work was done on winter soil respiration rates in snow covered systems, presumably because at low temperatures microbial activity is relatively low. However, while winter fluxes are indeed generally lower than growing season fluxes, they still represent a significant carbon loss from soils. Brooks et al. (1996) and others have demonstrated that microbial activity beneath seasonal snowpacks is not only significant, but also contributes to moderating nitrogen cycling before plants become active. Soil microorganisms are thought to be active at temperatures as low as -5 to -7 ˚C (Brooks et al. 2005) and further work on winter soil C efflux has shown that the development of seasonal snow cover exerts a strong control on the magnitude of C fluxes. Years with reduced snowpack are accompanied by significantly lower soil C efflux, which has been attributed to the insulating effect of snow and to the development of a unique microbial community that exhibits high rates of substrate utilization at cold temperatures beneath snow (Monson et al. 2006). Other studies have shown that while subnivian microbial communities may be highly productive, C-limitation may limit rates of winter soil respiration (Brooks et al. 2005). Additional process level controls on winter CO_2 efflux include: freeze-thaw cycles, sub-nivean soil temperature and soil moisture availability (Liptzin et al. 2009). Oquist et al. (2009) showed that microbial responses to temperature variation at sub-zero temperatures are in fact closely linked to moisture deficiency caused by the freezing of soil water, and that the amount of unfrozen water present in frozen soils is, in fact, dependent on the quality of organic matter in the soil.

Harrysson-Drotz et al. (2009) further demonstrated that soil texture and physical properties also control the proportion of liquid water present at sub-zero temperatures. They found that both matric and osmotic potential contributed to controlling the liquid water content of the soils, and they suggested that the larger the pores containing unfrozen water, the more microbial activity can be sustained. It appears that as soils freeze, the environmental factor predominantly controlling heterotrophic CO_2 production in sub-zero soils may change. Not only the amount but also the composition of SOM affects the pore size distribution and thus the unfrozen water content, and under these conditions microbes appear to respond primarily to water availability. Due to the complexity of this system, winter climate plays a significant role in regulating soil C efflux.

The principal goals of this study were to determine the relative magnitudes of gaseous and dissolved fluxes of carbon from near surface soils and to quantify the primary controls on these fluxes. I hypothesized that water availability would be the principal limiting factor on mobilization of carbon from near surface soils, and water availability in these systems is critically linked to climate. My objectives were to quantify the role of inter-annual and seasonal climate variability in driving soil carbon flux, and to address the role of soil texture in moderating the response of soil fluxes to climate.

Site Characterization

Dissolved and gaseous carbon fluxes were measured for two subalpine sites in the Jemez-Santa Catalina Critical Zone Observatory (JSC-CZO) which is located in Southern Arizona and Northern New Mexico (Figure 1). Sites in both the NM and AZ locations of the JSC-CZO were employed. While both are characterized by subalpine mixed-conifer forests with distinctly bimodal precipitation and soil moisture regimes, they differ in that the Valles Caldera site (Jemez Mountains, NM) is subjected to seasonal snowpack developments during winter months that may vary in duration, whereas at the Marshall Gulch site (Santa Catalina Mountains, AZ) snowpack development is ephemeral and varies significantly.

Within the Marshall Gulch basin two sub-sites with distinct parent materials and soil types were identified. Both sub-sites have comparable slope, aspect and vegetation species assemblages, are at approximately the same elevation, and are subjected to the same climatic conditions (Table 1). The two sub-sites are distinct in that in that one is underlain by a granitic parent material that weathers to produce a coarse-grained soil, while the other is underlain by schist that weathers into a finer-grained soil (Table 1). The schist soils are deeper than the granitic soils, with lower hydraulic conductivity, higher moisture retention capacity, and longer water residence times than the granitic soils (Heidbüchel et al. in prep.). Leaf area index (LAI), a unitless index calculated from LIDAR (Light Detection and Ranging) and used as a proxy for vegetation productivity in previous soil respiration studies (Reichstein et al. 2003), was significantly higher at the schist site (Table 1). LAI was calculated based on the method of Lim et al. (2003) as used by Richardson et al. (2009). Soil bulk C content, measured for surface soil samples at all sites at the UC Davis Stable Isotope Laboratory, was also higher at the schist site than at the granite site.

The sites in Arizona and New Mexico provide a climate comparison while the distinct soil types facilitate an analysis of how soil texture can moderate the response of soil carbon loss to climate variability.

Experimental Design and Methods

Experimental Design

Two sites were established at Marshall Gulch (AZ) within the areas characterized by granite and schist soils. At Valles Caldera (NM), sites were established in healthy mixed conifer forest stands, mixed conifer stands impacted by *Choristoneura occidentalis* (western spruce budworm), and subalpine meadow. At each site three 1 m^2 plots were selected.

DOC flux was sampled during each precipitation season (spring snow melt and summer monsoon) through 2010 and 2011. At each plot, three DOC samples were collected during each season. CO_2 samples were collected before, during and after each precipitation season through 2010 and 2011. Because CO_2 flux is generated by both heterotrophic and autotrophic activity when plants are active and by heterotrophic activity alone when plants are dormant, for seasonal comparisons of CO_2 flux the seasons were defined based on growing season. Monson et al. (2005) showed through eddy covariance methods that plants respond rapidly as soon as liquid water becomes available during snowmelt. I defined seasons as ‘winter’ during the snow accumulation period when plants are senescent, and ‘growing season’ from peak snow water equivalent (SWE) to beginning of next accumulation period when plants are active.

Climate data

Precipitation and air temperature data were collected by RAINEW 111 Tipping Bucket Wired Rain Gauges and a HOBO U20-001-01 probe and data logger at Marshall Gulch (AZ), and snow depth and duration was measured at a meteorological station located approximately 3 km from Marshall Gulch at comparable elevation. At the Valles Caldera (NM) precipitation, air temperature and snow depth and duration data were measured at a meteorological station adjacent to the site.

Soil temperature was measured in situ using a thermometer inserted into the top 10 cm of the soil surface. Soil cores 7-10 cm deep and 4 cm in diameter were collected before and after each precipitation season. In the lab, the soils samples were homogenized and dried at 105 °C. Gravimetric soil moisture was determined from the mass difference between field-moist and oven-dry soils.

DOC Flux

To obtain a quantitative estimate of the DOC flux associated with each precipitation season, mixed bed ion exchange resin traps were installed at 10 cm depth prior to the onset of each precipitation season to capture DOC leached from surface soils (O/A soil horizon). The traps were designed according to the method of Brooks et al. (1999) and consisted of ~20 cubic centimeters of mixed anion and cation exchange resins (J.T. Baker, IONAC NM-60 H^+/OH^- Form, 16-50 Mesh) sewn into acid-washed nylon bags and secured within 1.5 cm-diameter PVC pipe open at the top and bottom to collect leachate from overlying soils. The traps were installed by removing an intact block of soil, installing the trap and then replacing the soil. Traps were recovered at the end of the season and processed in the laboratory where they were air dried and extracted with 2M KCl (1:5, weight:volume). Extracts were filtered through Whatman 1 paper filters and stored at 4°C until processing.

DIC Flux

Fluxes of DIC were estimated based on mean soil pH and a range of soil pCO_2 values. The mean pH of the schist and granite soils were 5.9 and 6.6, respectively. At this pH range, DIC concentration can be approximated as the summed concentrations of carbonic acid and bicarbonate:

$$[DIC] = [H_2CO_3^0] + [HCO_3^-]$$

Assuming that concentration is approximately equal to activity, $[H_2CO_3^0]$ and $[HCO_3^-]$ can be calculated according to the following equations:

$$[H_2CO_3^0] = \frac{K_1 K_{\mathrm{CO2}} pCO_2}{[H^+]}$$

$$[HCO_3^-] = \frac{[H^+]\,[H_2CO_3^0]}{K_1}$$

Where $[H_2CO_3^0]$, $[HCO_3^-]$and $[H^+]$ are concentrations, K_1 and $K_{\mathrm{CO}_2}$are equilibrium constants corrected for soil temperature and pressure conditions, and pCO_2 is the partial pressure of CO_2 within the soil. Measurements of soil pCO_2 were not available so pCO_2 values were estimated based on CO_2 concentration measurements from the base of the snowpack and compared with values of soil pCO_2 cited in the literature. In order to convert DIC concentration into seasonal and annual fluxes the concentration of DIC in soil solution was multiplied by cumulative seasonal and annual precipitation. Cumulative precipitation is probably an overestimate of the total moisture flux for these systems, given that some quantity of precipitation is lost to evapotranspiration/sublimation, runoff, etc.

CO_2 Flux

CO_2 was measured in situ using a portable infrared gas analyzer (IRGA, PP Systems, EM-4). During snow-free periods, a chamber attachment was used with the IRGA. During snow-covered periods CO_2 flux was estimated by measuring the concentration of CO_2 at 10 cm intervals through the snowpack. Fluxes were calculated from the vertical concentration profile using a steady state diffusion model based on Fick's Law:

$$\boldsymbol{J_{CO_2} = D_{CO_2}\left(\frac{d[C_{CO_2}]}{dz}\right)f}$$

Where $\boldsymbol{J_{CO_2}}$ is the flux, $\boldsymbol{D_{CO_2}}$ is a diffusion coefficient, $\boldsymbol{z}$ is the depth of the snowpack, and $\boldsymbol{f}$ is the porosity of the snowpack. The diffusion coefficient $\boldsymbol{D_{CO_2}}$was assumed to be 0.139 for CO_2 gas, consistent with Sommerfeld et al. (1993) and Brooks et al. (1996, 1999). Porosity was calculated as the inverse of snowpack density. Molar gas volumes were corrected for local temperature and pressure conditions.

2.4 Statistical Analysis:

All statistical analyses were performed using JMP 9 software (SAS System, 2007). I used the Wilcoxan/Kruskal-Wallis rank sums test for non-parametric data to determine if mean dissolved and gaseous fluxes and mean soil moisture varied significantly between seasons, years and sites. I regressed gaseous flux against soil temperature and soil moisture to identify how fluxes varied with climate, and against bulk soil C and LAI to identify how fluxes varied with biological variables. I used a multiple linear regression model to predict gaseous flux using gravimetric soil moisture and bulk soil C.

Results

3.1 Climate data

Total precipitation at Marshall Gulch during 2010 was 813 mm, of which 315 mm fell as snow during the winter; the remaining 498 mm fell as summer (monsoon) rain (Figure 3). During 2011, the total precipitation at this site was slightly more than half that of the previous year (461 mm), with 52 mm falling during winter as snow and rain, and the remaining 409 mm falling as summer rain. During the winter of 2010, the snow cover was consistent and lasted from 1 December 2009 through 18 April 2010 (139 days). During the winter of 2011 no significant snowpack developed; infrequent storm events produced an ephemeral snowpack that accumulated and ablated between 29 December 2010 through 3 March 2011 (64 days, Figure 3).

Cumulative annual precipitation at Valles Caldera during 2010 was 658 mm, of which 293 mm fell as snow during the winter and 365 mm fell as summer rain. The site remained snow covered from 7 December 2009-28 April 2010 (143 days). During 2011, the cumulative annual precipitation at this site was also much lower than in 2010 (546 mm). Winter precipitation was 226 mm, and the site remained snow-covered for 134 days from 16 December 2010-28 March 2011. Summer precipitation in 2011 was 320 mm.

Winter soil temperatures ranged from 0°C to -4°C. There was no significant difference in soil temperature between years, soil types, or continuously snow covered soils and ephemerally snow covered soils. During summer, soil temperatures ranged from

0 °C to 25.3 °C, and there was no significant difference in soil temperature between soil types or years.

During winter, gravimetric soil moisture at ephemerally covered sites ranged from 37.8% to 64.1%, while at the continuously covered sites it ranged from 17.6% to 73.2%. There was no significant difference in soil moisture between continuously covered and ephemerally covered sites. During summer, soil moisture ranged from 1.7 to 78.9 %. Although there was no significant difference with soil type under dry conditions (during the pre-monsoon summer), under wet conditions the schist soil had significantly higher soil moisture ($p < 0.05$).

3.2 DOC Flux

Dissolved C fluxes varied from 6.1 ± 0.36 g C m^{-2} y^{-1} to 8.8 ± 0.52 g C m^{-2} y^{-1}. In general, mean fluxes were higher in summer (4.30 ± 0.28 g C m^{-2}) than in winter (3.45 ± 0.16 g C m^{-2}, Table 4). There was no significant difference between mean fluxes during 2010 and 2011 despite dramatic inter-annual variability in precipitation quantity. There was no significant relationship with soil type at the Marshall Gulch sites; however, normalizing the dissolved fluxes by bulk soil carbon showed that more carbon was lost from schist soils than from granitic soils relative to bulk soil carbon (Figure 5). DOC fluxes were not significantly related to CO_2 fluxes, and furthermore, relative to the magnitude and variability observed among gaseous fluxes DOC fluxes were small (Figure 6).

Due to the high degree of uncertainty in soil pCO_2, fluxes of DIC are approximate. Using pCO_2 values estimated based on mean measured CO_2 concentrations at the base of the snowpack, DIC flux at the granite site was 1.2 g C m^{-2} yr^{-1} during 2011during 2010 and 0.8 g C m^{-2} yr^{-1} during 2011. At the schist site DIC flux under these conditions was 3.2 and 1.6 g C m^{-2} yr^{-1} for 2010 and 2011, respectively. These values are almost certainly underestimating DIC flux because the partial pressure of CO_2 is likely to be higher within the soil profile than at the soil surface. To gain an idea of how much larger DIC fluxes might be I re-calculated the fluxes based on values of soil pCO_2 cited in the literature for both experimental and modeled data (Johnson et al. 1994, Jones and Mulholland 1998, Andrews and Schlesinger 2001, Karberg et al 2005), which ranged from 0.8 – 3.0 % for surface soils (from 0 – 30 cm). Based on these values, DIC flux ranged from 2.3 – 17.5 g C m^{-2} yr^{-1} at the granite site and from 4.3 – 31.7 g C m^{-2} yr^{-1} at the schist site.

3.3 CO_2 Flux

During winter, CO_2 flux from sites with continuous snow cover at Marshall Gulch (AZ) and Valles Caldera (NM) ranged from 0.48 to 3.91 g C m^{-2} d^{-1}, while sites with ephemeral snow cover at Marshall Gulch (AZ) exhibited low flux rates (from 0 to 0.22 g C m^{-2} d^{-1}). Neither the consistently snow covered sites nor the ephemerally covered sites showed any relationship between soil temperature and CO_2 efflux (Figure 8). No relationship between CO_2 flux and gravimetric soil moisture was observed at the ephemeral sites where fluxes were low; however, at the continuously covered sites there was a significant positive relationship between soil moisture and CO_2 flux ($R^2 = 0.35$, $p = 0.0071$, Figure 9). A multiple linear regression model that included both soil moisture and bulk soil carbon predicted 55% of the variability in CO_2 efflux at the continuously snow covered sites.

During summer, CO_2 efflux at all sites ranged from 0.72 ± 0.12 to 5.27 ± 0.31 g C m^{-2} d^{-1}. Again, fluxes during 2010 were significantly higher than during 2011. During 2010, mean summer CO_2 efflux from the schist-derived soil was significantly higher than that from the granite (Figure 10). The relationship between soil temperature and CO_2 efflux shows high fluxes between 8 and 15 °C and lower fluxes both above and below this range (Figure 11). There was a strong positive relationship between soil moisture and CO_2 flux (Figure 12). Soil moisture explained 36% ($p = 0.0063$) of the variability observed at the granite site and 90% ($p < 0.0001$) of the variability observed at the schist site (Figure 12). There was no significant relationship between mean summer CO_2 efflux and LAI. Normalizing CO_2 efflux by LAI decreased the difference in CO_2 flux between the schist and granite sites but did not alter the significant patterns.

Discussion

DOC flux values are low but well within the range of values reported in the literature which range from 2-84 g C m^{-2} yr^{-1} (Yavitt and Fahey 1986, Moore 1989, Qualls et al. 1991, Currie et al. 1996, Brooks et al. 1999, Michaelzik and Matzner 1999, Kindler et al 2011). They compare well with fluxes reported from similar ecosystems: 10.6 g C m^{-2} y^{-1} at a lodgepole pine forest near Medicine Bow, WY (Yavitt and Fahey, 1986), and 6.5 g C m^{-2} y^{-1} at European spruce forests (Kindler et al 2011). In general, mean fluxes were higher in summer (4.30 ± 0.28 g C m^{-2}) than in winter (3.45 ± 0.16 g C m^{-2}, Figure 4), indicating that more carbon is mobilized by moisture flux emanating from monsoon rains than from snowmelt. This could be due to limited moisture flux available to mobilize and transport DOC, but no relationship was observed between cumulative seasonal precipitation and DOC flux, suggesting that moisture flux is not a limiting factor.

Although the schist soils contained higher bulk soil C than the granitic soils (Table 1), there was no significant difference in DOC flux between schist and granitic soils. Normalizing DOC flux to bulk soil C shows that the schist soils experience higher DOC losses relative to total bulk soil C content. In addition to higher bulk soil C, the schist soils have a larger clay fraction, a higher cation exchange capacity and a lower base saturation as compared to the granitic soils (Table 2), suggesting that while more carbon may be present in this soil it also is more likely to be bound to mineral surfaces and/or particulate organic and thus protected from leaching or microbial degradation (Nelson et al. 1993).

Values of DIC flux based on pCO_2 at the snow-soil interface are on the low end of the range of published values of DIC flux from surface soils which range from 2 to 48 g C m^{-2} yr^{-1} (Jones and Mulholland 1998, Kindler et al. 2011). This may suggest that while the DIC flux values based on the CO_2 concentration at the soil-snow interface are not unreasonable, they likely underestimate the total DIC flux. A more precise estimate of soil pCO_2 would provide much more accurate results for DIC flux from this system. Given the large uncertainty in pCO_2 estimates, it is difficult to predict the effect of DIC flux on ecosystem carbon balance; however, even the low values of DIC flux significantly increase the total loss of dissolved C from soils.

There was not a significant relationship between DOC flux and CO_2 flux. Furthermore, the relative amount of soil carbon lost via DOC leaching was far smaller and less variable than the gaseous flux (Figure 6). During winter, there was significantly higher soil CO_2 efflux from sites with continuous snow cover than sites with ephemeral snow cover, and the values were on the high end of the range of values observed for montane systems during the snow covered season (Brooks et al. 2005, Sommerfeld et al. 1993, Suni et al. 2003, McDowell et al. 2000). The lower carbon flux associated with decreased snow cover is consistent with observations by Monson et al. (2006), who demonstrated a significant relationship between snow cover and soil temperature, where soil temperature correlated positively with soil CO_2 efflux. This study showed no relationship between soil temperature and CO_2 efflux, consistent with other observations of winter soil CO_2 efflux (Sommerfeld et al. 1993, Brooks et al. 1997, Brooks et al. 2005). There was a significant correlation between subnivean soil moisture and soil CO_2 efflux (R^2=0.35, $p<0.0071$, Figure 9), suggesting that rather than temperature, soil moisture is the dominant control on winter soil carbon loss at these sites. The amount of liquid water present in soils at sub-zero temperatures has been shown to vary with matric and osmotic potentials (Harrysson-Drotz et al. 2009) and with the quality and quantity of soil organic carbon (Oquist et al. 2009). By including gravimetric soil moisture and bulk soil carbon in a multiple linear regression model, I was able to improve my ability to predict soil CO_2 efflux at continuously snow covered sites (R^2=0.55, $p<0.0062$), suggesting that soil carbon content positively correlates with gas flux either by moderating liquid soil water content or by providing a food source to microbes.

The relationship between soil temperature and mean gas flux during summer suggests an optimal range of temperature between approximately 8 and 15 °C where fluxes are high, bounded on either end by less optimal temperature conditions (Figure 11). This pattern suggests that soil respiration is temperature limited below approximately 8 °C, and moisture limited above approximately 15 °C; these observations are consistent with previous studies in moisture limited systems (e.g. Davidson et al. 1998).

The differential response of gas flux to soil moisture at the granitic and schist soils can be related to soil texture. During 2010 under wetter conditions, gravimetric soil moisture at the schist site was significantly greater than at the granite site (Figure 13), and Heidbüchel et al. (in prep.) observed both longer residence times, higher water holding capacity, and lower saturated hydraulic conductivity at the schist site compared with the granite site. The lower clay content, larger pore size and shallower soil horizons at the granite site make it more susceptible to rapid drying after precipitation events, while the higher clay content, smaller pore size, and deeper soil horizons of the schist soil more effectively retain water under wet conditions.

The low correlation between LAI and CO_2 efflux and higher LAI-normalized CO_2 flux from the schist site during summer 2010 suggest that while vegetation productivity may contribute to higher fluxes overall, it cannot fully explain the difference between the granite and schist soils. These results suggest that soil moisture limits both autotrophic and heterotrophic soil respiration.

Conclusions

Although dissolved organic and inorganic C fluxes in these systems are small relative to gaseous fluxes, they represent a significant loss of carbon from soils and are relevant to system carbon balance. DOC fluxes are controlled by C production and soil mineralogy. DIC fluxes are driven by moisture flux and the partial pressure of CO_2 in the soil profile. Gaseous fluxes both in summer and winter are controlled by moisture availability and are sensitive to inter-annual climate variability. During wet years, gaseous soil C fluxes are significantly higher than during dry years both in winter and summer. Soil CO_2 flux during winter is dependent on precipitation and soil C content. Snow insulates the soil, while soil C content controls the amount of liquid water present in the soil. Winter soil C-loss is principally controlled by moisture availability. During summer, soil respiration is also directly controlled by moisture availability. Furthermore, during wet summers, the physical properties of the soils modulate the response of soil respiration to climate, as fine soils that more effectively retain moisture have higher rates of gaseous C-loss. The implications if these findings are significant in the context of how montane forest systems respond to predicted changes in climate.

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APPENDIX B: DISSOLVED AND EXTRACTABLE SOIL CARBON DYNAMICS

Introduction

The strongly bimodal precipitation regime that dominates these sites produces two distinct pulses of soil moisture each year. I hypothesized that soluble organic C in the soil profile would be mobilized by snowmelt and monsoon rains in the spring and summer, respectively. Brooks et al. (1999) observed a linear relationship between the amount of C leached from soils during snowmelt in the Colorado Rockies and the amount that could be extracted from soils in the laboratory, suggesting that the more soluble C that was present in the soils, the more would be leached during snowmelt. I measured leached DOC and water-extractable soil C to see if this relationship was true for the more arid montane systems in my study. I analyzed soils in the laboratory for water-extractable organic C before the onset of the melt and monsoon seasons and again at the end of each season. By comparing the amount of water soluble C present in soils before each precipitation season with the amount of C leached during the season and the amount of soluble C remaining in the soil at the end of the season I hoped to provide insight into seasonal rates of decomposition and C-cycling within the soil.

Methods

DOC Flux was quantified by installing three mixed bed ion exchange resin traps in each plot at 10cm depth prior to the onset of each precipitation season to capture DOC leached from surface soils (O/A soil horizon). The traps were constructed based on the design used by Brooks et al. (1999) and consisted of ~20 cm^3 of mixed anion and cation exchange resins (J.T. Baker, IONAC NM-60 H^+/OH^- Form, 16-50 Mesh) in acid-washed nylon bags, secured in 1.5 cm-diameter PVC pipe open at the top and bottom to collect leachate from overlying soils. The traps were installed by removing an intact block of soil, installing the trap and then replacing the soil. Traps were recovered at the end of the season and processed in the laboratory where they were air dried and extracted with 2M KCl (1:5, weight:volume). Extracts were filtered through Whatman 1 paper filters and stored at 4°C until processing for TOC and TN on a Shimadzu Total Carbon Analyzer.

At each plot prior to the onset of the snowmelt/monsoon season and concurrent with the installation of the resin traps I collected three intact soil cores from the top 10 cm of the soil profile (the O/A soil horizon). At the end of the season, when I recovered the resins I re-sampled the soils. After collection in the field, soil cores were placed in Ziplock bags and stored at 4°C until processing in the lab. All soils were processed within 48 hours of collection. Soils were homogenized using 2 mm soil sieves. Subsamples were weighed and dried at 105 °C to estimate gravimetric soil moisture. A second subsample was extracted in a 1:5 (soil:dionized water) ratio in a combusted glass Erlenmeyer flask. The soil-water slurry was covered and agitated on a shaker table for 1 hour. The slurry was centrifuged (g-force = 1400) for 2 minutes, and then filtered through Whatman GF/F combusted glass fiber filters using combusted glass filter pods. After filtering, the extracts were stored in combusted amber glass bottles; all extracts were analyzed on a Shimadzu Total Carbon Analyzer for NPOC and TN.

Results

Dissolved C fluxes varied from 10.85 ± 2.46 to 3.18 ± 0.20 g C m^{-2} y^{-1}. In general, mean fluxes were higher in summer (4.30 ± 0.28 g C m^{-2}) than in winter (3.45 ± 0.16 g C m^{-2}, Table 4), but no relationship was observed between cumulative seasonal precipitation and DOC flux. Mean extractable DOC ranged from 2.57 ± 0.57 to 121.98 ± 10.85 g C m^{-2} (Table B.1). There was no clear relationship between extractable DOC and leached DOC, nor did extractable DOC vary predictably with season. Significantly higher and more variable values were observed at the sites in New Mexico (2.57 ± 0.57 to 121.98 ± 10.85 g C m^{-2}) than at sites in Arizona (3.35 ± 0.20 to 15.89 ± 1.11 g C m^{-2}; Table B.1). While there was not a consistent relationship with soil type, the schist soil was generally higher than the granite. Within the sites in New Mexico, the meadow soils had significantly lower extractable DOC values than the forest soils, and soils from the spruce budworm impacted forest generally had higher extractable C than healthy forest soils (Table B.1).

Discussion

Contrary to initial expectations, I observed no relationship between leached DOC and water-extractable DOC, but this is likely due to low variability in DOC flux. The extraction process simulated a scenario in which moisture is abundant, soils are saturated and the maximum concentration of soluble C is in solution. No relationship was observed between moisture flux (cumulative seasonal precipitation) and DOC flux, suggesting that moisture limitation was not controlling DOC flux.

The strongest control on the magnitude of extractable DOC appears to be linked to vegetation type (forest vs. meadow) and condition (spruce bud-worm impact), perhaps suggesting that litter input and decomposition processes are the predominant drivers of DOC production in soils. However, more research is necessary to elucidate how DOC production subsequently influences rates of dissolved C-loss.

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APPENDIX C: EFFECTS OF VEGETATION

C.1 Vegetation Type: Healthy Forest and Meadow

Introduction

To better constrain the total carbon losses from the Valles Caldera site, I measured dissolved and gaseous carbon fluxes from subalpine meadow to compare with fluxes from healthy mixed conifer forest. Approximately 30% of the landcover is subalpine meadow consisting of grasses and forbes, while the remaining fraction of land cover consists of regenerating stands of mixed conifer forest. By quantifying carbon fluxes from both of these vegetation types I hope to improve estimates of carbon losses from the ecosystem.

Methods

(Please see Appendix A for methods)

Results

We observed significantly higher fluxes from both forest and meadow soils during summer than during winter, and during summer forested sites had significantly higher dissolved fluxes than meadow sites (Figure C.1, Table 4). Gaseous fluxes were also significantly higher during summer than during winter 2011; however, during summer gaseous fluxes from meadow soils were higher than those from forest soils (Figure C.2, Table 5).

Discussion

These sites are located within an area of one square kilometer at comparable elevations and with similar slopes and aspects (Table 1), so they are likely exposed to the same climatic conditions. No differences in dissolved or gaseous fluxes between vegetation types were observed during winter (FigureC.1, Figure C.2), suggesting that when plants are inactive, these sites respond similarly to environmental conditions.

During summer I observed higher gaseous fluxes from the meadow sites (Figure C.2). This may in part be explained by the fact that grasses and forbes are perennial and annual species that put on biomass during the growing season and then subsequently die back in the fall. Completing their life cycle during the warm summer months requires rapid growth and carbon uptake during the snow-free season. Conversely, trees accumulate biomass over years, and are known to begin photosynthesizing rapidly in response to the first pulse of liquid water following the onset of snowmelt (Monson et al. 2005). Hence, the growing season of trees is longer than that of grasses and forbes, and they retain carbon from year to year. If increased rates of C-uptake correspond with increased rates of respiration, this might explain why the meadow soils have higher carbon flux during summer.

The higher dissolved fluxes observed during summer from forest soils (Figure C.1) correspond with higher bulk C measured at these sites relative to the meadow sites (Table 1). Furthermore, the quality of carbon in the forest soils may make it more susceptible to leaching; however, further research is necessary to investigate the quality of soil carbon at these sites.

C.2 Vegetation Disturbance: Spruce Budworm Impact

Introduction

Throughout western North America, *Cronistoneura occidentalis* (western spruce budworm) has caused widespread damage to coniferous forests. It is found in the Rocky Mountains as far south as Arizona and as far north as Alberta and British Colombia. *C. occidentalis* was first reported in Canada in 1909 and in the United States in 1914. Since the 1920s widespread and destructive outbreaks have been relatively frequent, although no clear pattern or trend in epidemics has been observed. While in some cases outbreaks have been known to last a few years and then subside naturally, others have persisted much longer. Spruce budworm causes damage through defoliation. Its larvae devour the new spring growth of Douglas fir and most spruce and fir species. In some cases this is minor and the tree may be relatively unaffected; in other cases it can be severe, leading to reduced tree growth, top-killing, and some tree mortality. New growth, saplings and pole-sized trees are often targeted over mature trees, and mortality among young trees is often higher (Fellin and Dewey, 1982).

The forests at the Valles Caldera site are variably impacted by *C. occidentalis*. One side effect of the insect infestation is that impacted stands drop more needles than healthy stands, and additional detritus produced by the insects themselves also provides and additional input to the soil carbon pool. To quantify the effect of *C. occidentalis* infestation on soil carbon dynamics I compared the magnitude of soil carbon pools and fluxes between healthy and impacted mixed conifer forest.

Methods

(Please see Appendix A and Appendix B1 for methods)

Results

Sites impacted by *C. occidentalis* showed no clear seasonal pattern in DOC flux. In 2010 there was no significant difference between winter and summer fluxes, while in 2011 summer fluxes were significantly higher than winter (Figure C.3). Gaseous fluxes did not show a clear temporal pattern either. During 2010 summer fluxes were high and winter fluxes were low, while during 2011 winter fluxes were high (although not as high as the previous summer) and summer fluxes were extremely low (Figure C.4).

Discussion

Soils at sites impacted by *C. occidentalis* had rates of DOC flux comparable with other sites (Table 4), despite having significantly higher bulk soil C (Table 1) and organic matter content (Table 2). Despite the high rates of litter and detritus input to the soils due to insect activity, the soils do exhibit higher rates of either dissolved or gaseous carbon losses compared to soils in healthy forests and meadows at adjacent sites (Table 4, Table 5). Gaseous losses do not have a clear seasonal pattern either (Figure C.4); however, compared with observations of summer soil respiration at the impacted site during 2010 and with observations from other sites during both years, the impacted site experienced very low fluxes during summer of 2011 (Table 5). In fact, these rates compare well with winter respiration rates; however, more research is necessary to determine the relative contributions of autotrophic and heterotrophic respiration to total soil respiration under insect-impacted conditions.

Low rates of carbon loss coupled with large amounts of litter and detritus input might suggest that these soils may be acting at least temporarily as a net carbon sink. However, the apparent ability of these soils to retain large amounts of organic carbon may be due to the rate at which litter and detritus decompose. It may also be affected by the quality of soil carbon at these sites. More research is necessary to determine the effects of substrate quality as well as to observe how these sites respond to the increased litter and detritus inputs over time.

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APPENDIX D: EFFECTS OF ASPECT

Introduction

To assess the effect of aspect on soil carbon processes and to further constrain ecosystem soil carbon losses, I compared how fluxes of carbon vary between northeast-facing and southwest-facing forests and meadows. Rasmussen et al. (2005) suggest that the energy entering an ecosystem may have implications for soil and ecosystem development. Based on ongoing work described in more detail by Chorover et al. (2011), I hypothesize that ecosystems organize and evolve in response to open system fluxes of energy and mass, including meteoric inputs of radiation, water, and carbon, which can be quantified at point to watershed scales. Furthermore, positive feedbacks between moisture and carbon dynamics moderate the rate at which fluxes of both moisture and carbon move through the system but are subject to topographic controls. The variability of soil moisture with aspect has been studied extensively (e.g. Hanna et al. 1982, Western et al. 1999, Ivanov et al. 2010). Furthermore, the current study and many others have demonstrated a strong positive relationship between soil moisture and soil carbon flux. It thus stands to reason that in systems where soil moisture varies with aspect soil CO_2 efflux will also vary with aspect. To better understand how soil carbon losses are affected by energy inputs to the system, I looked at how soil carbon fluxes vary between Northeast and Southwest aspects. Kang et al. (2003) observed higher rates of soil respiration from north-facing hillslopes in Korea despite the fact that soil temperature was the primary control on soil respiration, explaining up to 96% of the variance in soil respiration at their sites. Aspect, however, is not the only topographic control acting on CO_2 efflux. Riveros-Iregui et al. (2009) showed that in addition to aspect, upslope contributing area also significantly controlled rates of soil CO_2 efflux, and Barron-Gafford et al. (in prep.) expand on the role of complex terrain in moderating soil CO_2 efflux. To improve my ability to estimate ecosystem soil carbon losses, I measured soil respiration from sites with distinct aspects in an arid region where soil moisture is known to strongly control CO_2 efflux.

Methods

(Please see Appendix A for methods)

Results

There was no significant difference in dissolved fluxes between forests with northeast and southwest aspects; however, southwest-facing meadows had lower dissolved fluxes than northwest-facing meadows. The fluxes from northeast-facing meadows were comparable with those from forests (Figure D.1). Gaseous fluxes were significantly higher from forests and meadows with northeast aspects than those with southwest aspects (Figure D.2).

Discussion

While the effect of aspect on dissolved C fluxes was minimal, it appears to exert a significant control on gaseous C fluxes. Gaseous fluxes are known to respond to many environmental factors. To minimize the confounding effects, the sites used in this comparison were located at comparable elevations within one square kilometer of one another, so climatic conditions were constant, and sites were selected to have comparable slope and topographic contributing index (TCI) (Table 1). However, despite receiving the same precipitation and experiencing the same air temperature conditions, mean soil moisture was significantly higher during both summer and winter at northeast-facing meadow and forest sites (Table 3). Due to the strong relationship between soil moisture and CO_2 efflux, it is not surprising that I observe higher flux rates from the sites with higher soil moisture.

The relationship between aspect and soil moisture is widely recognized and has been the subject of many studies (Hanna et al. 1982, Western et al. 1999, Ivanov et al. 2010); however, the implications of this relationship for soil carbon balance could be significant. Given the need to better constrain inputs to carbon balance models, the relationship between soil moisture and soil respiration across different aspects necessitates further research.

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APPENDIX E: DATA

E.1 Leached DOC and TN Data

Summary

Data collected for leached DOC flux according to the method described in Appendix A is presented in Table E.1. Each time leached DOC data was collected I simultaneously analyzed the total nitrogen (TN) content of the resin extracts. Nitrogen fluxes can be estimated from the resin trap method discussed in Appendix A, but nitrogen data analysis was not included in the study presented here.

E.2: Gravimetric Soil Moisture, Extractable DOC and Extractable N Data

Summary

Data collected for extractable soil C according to the method described in Appendix B is presented in Table E.2. Extractable nitrogen was estimated using the same method. Neither extractable C or N was included in the study presented here. Gravimetric soil moisture data is also presented in Table E.2.

E.3: Gas Flux Data

Summary

Gas flux data collected according to the methods described in Appendix A is presented in Table E.3.

E.4: Bulk Soil C, Bulk Soil N, and Stable Isotope Data

Summary

Bulk soil C, bulk soil N and stable isotopes of C and N were analyzed from bulk soil samples at the Stable Isotope Facility at UC Davis (Table E.4). Only the bulk soil C was included in the present study, but the nitrogen and isotopic data were collected because the analysis can be done along with bulk soil C for no additional cost.

APPENDIX F: TABLES

LIST OF TABLES

Table 1. Physical characteristics of the O/A horizon (0-10 cm depth) by site: bedrock and soil characteristics (sample depth, soil bulk density and bulk C), vegetation characteristics (vegetation type, leaf area index [LAI]) and topographic characteristics (elevation, slope, aspect and topographic contribution index [TCI]).

Site	Bedrock	Bulk Density	Bulk C (% mass)	Vegetation	LAI	Elev. (m)	Slope (deg)	Aspect	TCI
Santa Catalina Mountains									
Granite	Granite	0.9 ± 0.04	6.8 ± 0.28	Mixed Conifer	2.5 ± 0.02	2396	18.2	32.9	7.15
Schist	Schist	0.8 ± 0.04	8.1 ± 0.36	Mixed Conifer	3.2 ± 0.03	2349	24.2	30.3	7.50
Jemez River Basin									
Impacted	Tuff	0.9 ± 0.11	26 ± 2.1	Mixed Conifer, C. oc. impact	2.2 ± 0.01	3036	9.9	144.5	14.68
Healthy Forest SW	Tuff	n.a.	n.a.	Mixed Conifer	2.1 ± 0.02	3022	3.4	207.9	95.44
Healthy Forest 2 SW	Tuff	n.a.	n.a.	Mixed Conifer	1.2 ± 0.01	3037	4.9	235.4	15.46
Grass SW	Tuff	n.a.	n.a.	Meadow	0.68 ± 0.004	3037	6.5	286.9	17.61
Forest SW (ZOB)	Tuff	0.4 ± 0.05	18 ± 3.6	Mixed Conifer	1.5 ± .02	3023	5.5	225.1	8.49
Grass SW (ZOB)	Tuff	0.9 ± 0.15	8 ± 1.2	Meadow	0.63 ± 0.001	3021	5.9	223.0	17.78
Forest NE (ZOB)	Sandstone	2.2 ± 0.59	13 ± 1.4	Mixed Conifer	1.8 ± 0.03	3038	9.2	110.3	8.95
Grass NE (ZOB)	Sandstone	0.4 ± 0.05	11 ± 1.4	Meadow	0.8 ± 0.02	3026	11.8	131.3	16.78

Table 2. Soil Properties: bedrock and bedrock age, particle size distribution, soil organic matter (OM), base saturation and cation exchange capacity (CEC).

Site	Bedrock Type	Bedrock Age	Sample depth (cm)	Clay (%)	Silt (%)	Sand (%)	OM (%)	Base Sat. (%)	CEC (meq/100g)
Santa Catalina Mountains									
Granite	Granite	Eocene	0-25	6.9	36.4	56.7	9.4 ± 0.57	10	59.0
Schist	Schist	Middle Proterozoic	0-24	8.6	39.8	51.6	10.19 ± 0.99	28	208.6
Jemez River Basin									
Impacted	Tuff	Pleistocene	0-10	n.a.	n.a.	n.a.	38 ± 5.4	n.a.	n.a.
Healthy Forest SW	Tuff	Pleistocene	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Healthy Forest 2 SW	Tuff	Pleistocene	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Grass SW	Tuff	Pleistocene	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Forest SW (ZOB)	Tuff	Pleistocene	0-10	n.a.	n.a.	n.a.	17 ± 1.4	n.a.	n.a.
Grass SW (ZOB)	Tuff	Pleistocene	0-10	16.75	36.03	47.23	14 ± 2.3	n.a.	n.a.
Forest NE (ZOB)	Sandstone	Myocene	0-10	24.89	35.85	39.18	28 ± 3.5	n.a.	n.a.
Grass NE (ZOB)	Sandstone	Myocene	0-10	n.a.	n.a.	n.a.	18 ± 3.5	n.a.	n.a.

Table 3. Mean seasonal gravimetric soil moisture (%) ± standard error.

Site	**Winter 2010**	**Summer 2010**	**Winter 2011**	**Summer 2011**
Santa Catalina Mountains				
Granite	39 ± 3.6	16 ± 3.0	24 ± 3.8	11 ± 3.8
Schist	51 ± 3.3	25 ± 3.0	30 ± 3.8	12 ± 3.8
Jemez River Basin				
Impacted	n.a.	33 ± 3.8	46 ± 4.5	22 ± 2.2
Healthy Forest SW	n.a.	n.a.	n.a.	n.a.
Healthy Forest 2 SW	n.a.	28 ± 2.3	n.a.	n.a.
Grass SW	n.a.	32 ± 3.6	n.a.	n.a.
Forest SW (ZOB)	n.a.	n.a.	31 ± 5.0	23 ± 3.4
Grass SW (ZOB)	n.a.	n.a.	39 ± 5.4	22 ± 22
Forest NE (ZOB)	n.a.	n.a.	47 ± 4.6	45 ± 4.4
Grass NE (ZOB)	n.a.	n.a.	44 ± 4.1	31 ± 1.3

Table 4. Mean dissolved carbon flux (g C $m^{-2}season^{-1}$) ± standard error for snowmelt and monsoon seasons, 2010 and 2011.

Site	Winter 2010	Summer 2010	Winter 2011	Summer 2011
Santa Catalina Mountains				
Granite	3.7 ± 0.24	4.6 ± 0.68	3.2 ± 0.21	3.8 ± 0.37
Schist	3.5 ± 0.24	4.2 ± 0.44	3.4 ± 0.16	4.3 ± 0.39
Jemez River Basin				
Impacted	4.7 ± 0.36	4.1 ± 0.34	3.3 ± 0.35	5.5 ± 0.38
Healthy Forest SW	n.a.	n.a.	n.a.	n.a.
Healthy Forest 2 SW	n.a.	3.9 ± 0.34	n.a.	n.a.
Grass SW	n.a.	4.1 ± 0.34	n.a.	n.a.
Forest SW (ZOB)	n.a.	n.a.	2.9 ± 0.38	5.5 ± 0.36
Grass SW (ZOB)	n.a.	n.a.	2.5 ± 0.36	3.6 ± 0.36
Forest NE (ZOB)	n.a.	n.a.	2.9 ± 0.38	4.5 ± 0.38
Grass NE (ZOB)	n.a.	n.a.	3.9 ± 0.48	3.8 ± 0.41

Table 5. Mean gas flux (g $Cm^{-2}d^{-1}$) ± standard error for summer and winter, 2010 and 2011.

Site	**Winter 2010**	**Summer 2010**	**Winter 2011**	**Summer 2011**
Santa Catalina Mountains				
Granite	0.47 ± 0.03	2.0 ± 0.21	0.22 ± 0.04	1.2 ± 0.19
Schist	0.50 ± 0.03	4.3 ± 0.31	0.35 ± 0.06	1.5 ± 0.21
Jemez River Basin				
Impacted	0.49 ± 0.03	1.9 ± 0.19	0.5 ± 0.10	0.7 ± 0.12
Healthy Forest SW	0.35 ± 0.03	n.a.	n.a.	n.a.
Healthy Forest 2 SW	n.a.	2.86 ± 0.36	n.a.	n.a.
Grass SW	n.a.	1.73 ± 0.27	n.a.	n.a.
Forest SW (ZOB)	n.a.	n.a.	0.6 ± 0.11	2.7 ± 0.35
Grass SW (ZOB)	n.a.	n.a.	1.3 ± 0.17	3.3 ± 0.22
Forest NE (ZOB)	n.a.	n.a.	1.4 ± 0.23	3.4 ± 0.34
Grass NE (ZOB)	n.a.	n.a.	1.2 ± 0.22	5.3 ± 0.31

Table B.1. Mean water extractable DOC (g Cm^{-2}) ± standard error before and after each precipitation season, 2010 and 2011.

Site	Pre-Melt 2010	Post-Melt 2010	Pre-Monsoon 2010	Post-Monsoon 2010	Pre-Melt 2011	Post-Melt 2011	Pre-Monsoon 2011	Post-Monsoon 2011
Santa Catalina Mountains								
Granite	3.4 ± 0.20	4. 08± 0.50	6.9 ± 0.45	7.9 ± 0.69	7.6 ± 0.51	10 ± 1.2	13 ± 1. 8	3.3 ± 0.27
Schist	3.4 ± 0.48	4.4 ± 0.28	8.4 ± 0.64	13 ± 1.2	12.8 ± 0.82	6.4 ± 0.69	16 ± 1.1	2.3 ± 0.19
Jemez River Basin								
Impacted	n.a.	n.a.	53 ± 10.8	122 ± 10.9	70 ± 10.8	88 ± 10.9	114 ± 10.9	17 ± 11.5
Healthy Forest SW	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Healthy Forest 2 SW	n.a.	n.a.	38 ± 5.6	33.55 ± 7.75	n.a.	n.a.	n.a.	n.a.
Grass SW	n.a.	n.a.	4.7 ± 0.50	5.3 ± 0.60	n.a.	n.a.	n.a.	n.a.
Forest SW (ZOB)	n.a.	n.a.	n.a.	n.a.	35 ± 14.2	97 ± 20.1	70 ± 9.2	56 ± 9.3
Grass SW (ZOB)	n.a.	n.a.	n.a.	n.a.	6 ± 1.6	6 ± 1.0	6 ± 1.4	2.6 ± 0.57
Forest NE (ZOB)	n.a.	n.a.	n.a.	n.a.	32 ± 7.4	11 ± 2.0	9 ± 0.8	5.9 ± 0.69
Grass NE (ZOB)	n.a.	n.a.	n.a.	n.a.	14 ± 1.5	14 ± 1.2	34 ± 11.1	7 ± 1.3

Table E.1. Leached DOC and TN Data

Site	Plot	Date Collected	Leached C (gC/m^2)	Leached N (gN/m^2)
Forest	1	26-Sep-10	3.33	2.36
Forest	1	26-Sep-10	3.55	3.28
Forest	1	26-Sep-10	4.14	3.24
Forest	2	26-Sep-10	2.94	2.71
Forest	2	26-Sep-10	5.00	2.83
Forest	2	26-Sep-10	5.46	3.82
Forest	3	26-Sep-10	2.56	3.22
Forest	3	26-Sep-10	3.81	3.16
Forest	3	26-Sep-10	3.82	3.71
Forest (East)	1	27-May-11	1.52	0.79
Forest (East)	1	27-May-11	2.82	1.23
Forest (East)	1	27-May-11	4.33	1.95
Forest (East)	2	27-May-11	2.95	1.65
Forest (East)	2	27-May-11	3.28	1.78
Forest (East)	2	27-May-11	3.35	1.56
Forest (East)	3	27-May-11	2.03	1.04
Forest (East)	3	27-May-11	2.78	1.52
Forest (East)	1	23-Sep-11	4.49	3.40
Forest (East)	1	23-Sep-11	4.78	3.46
Forest (East)	1	23-Sep-11	5.53	3.87
Forest (East)	2	23-Sep-11	3.32	2.36
Forest (East)	2	23-Sep-11	3.52	2.48
Forest (East)	2	23-Sep-11	4.76	3.44
Forest (East)	3	23-Sep-11	3.72	2.56
Forest (East)	3	23-Sep-11	6.06	3.92
Forest (West)	1	27-May-11	2.16	1.18
Forest (West)	1	27-May-11	2.25	1.29
Forest (West)	1	27-May-11	2.90	1.49
Forest (West)	2	27-May-11	2.10	1.26
Forest (West)	2	27-May-11	2.18	1.27
Forest (West)	3	27-May-11	3.06	1.49
Forest (West)	3	27-May-11	3.23	2.06
Forest (West)	3	27-May-11	5.10	2.63
Forest (West)	1	23-Sep-11	3.67	2.85
Forest (West)	1	23-Sep-11	3.89	2.21
Forest (West)	1	23-Sep-11	4.38	2.17
Forest (West)	2	23-Sep-11	4.85	3.29
Forest (West)	2	23-Sep-11	7.42	3.09
Forest (West)	2	23-Sep-11	7.84	3.56
Forest (West)	3	23-Sep-11	4.77	3.22
Forest (West)	3	23-Sep-11	5.16	3.06
Forest (West)	3	23-Sep-11	7.37	3.06
Granite	1	1-May-10	3.25	0.54
Granite	1	1-May-10	3.60	0.74
Granite	1	1-May-10	5.09	0.69
Granite	2	1-May-10	2.74	0.41

Site	Plot	Date Collected	Leached C (gC/m^2)	Leached N (gN/m^2)
Granite	2	1-May-10	2.94	0.67
Granite	2	1-May-10	3.67	0.68
Granite	3	1-May-10	3.72	0.40
Granite	3	1-May-10	4.12	0.89
Granite	3	1-May-10	5.34	0.46
Granite	4	1-May-10	2.77	0.46
Granite	4	1-May-10	3.39	0.82
Granite	4	1-May-10	3.51	0.89
Granite	1	12-Sep-10	3.32	2.38
Granite	1	12-Sep-10	3.39	2.76
Granite	1	12-Sep-10	4.09	2.34
Granite	2	12-Sep-10	4.04	2.49
Granite	2	12-Sep-10	6.82	3.14
Granite	2	12-Sep-10	12.35	2.83
Granite	3	12-Sep-10	3.39	2.73
Granite	3	12-Sep-10	4.08	3.65
Granite	3	12-Sep-10	5.15	3.49
Granite	4	12-Sep-10	2.86	2.98
Granite	4	12-Sep-10	3.17	3.17
Granite	4	12-Sep-10	3.40	2.78
Granite	5	12-Sep-10	2.39	2.60
Granite	5	12-Sep-10	2.99	2.38
Granite	5	12-Sep-10	7.93	3.76
Granite	1	19-May-11	2.89	2.45
Granite	1	19-May-11	3.12	2.65
Granite	1	19-May-11	3.51	3.12
Granite	2	19-May-11	2.92	3.52
Granite	2	19-May-11	3.49	2.76
Granite	2	19-May-11	3.49	3.83
Granite	3	19-May-11	1.70	1.81
Granite	3	19-May-11	3.55	3.10
Granite	3	19-May-11	3.80	3.05
Granite	1	18-Sep-11	2.33	1.35
Granite	1	18-Sep-11	3.09	1.50
Granite	1	18-Sep-11	5.42	2.68
Granite	2	18-Sep-11	4.53	2.16
Granite	2	18-Sep-11	4.57	2.22
Granite	3	18-Sep-11	2.89	1.52
Granite	3	18-Sep-11	3.47	1.70
Granite	3	18-Sep-11	4.32	2.48
Impacted	1	26-May-10	3.84	0.43
Impacted	1	26-May-10	4.76	0.78
Impacted	2	26-May-10	4.67	0.47
Impacted	2	26-May-10	5.87	0.78
Impacted	2	26-May-10	7.11	0.76
Impacted	3	26-May-10	3.46	0.38
Impacted	3	26-May-10	3.78	0.37
Impacted	3	26-May-10	4.20	0.46
Impacted	1	26-Sep-10	2.95	3.19

Site	Plot	Date Collected	Leached C (gC/m^2)	Leached N (gN/m^2)
Impacted	1	26-Sep-10	3.16	3.39
Impacted	1	26-Sep-10	5.19	4.33
Impacted	2	26-Sep-10	3.51	2.28
Impacted	2	26-Sep-10	3.73	3.53
Impacted	2	26-Sep-10	5.69	2.76
Impacted	3	26-Sep-10	3.32	2.32
Impacted	3	26-Sep-10	3.88	2.61
Impacted	3	26-Sep-10	5.46	4.04
Impacted	1	27-May-11	2.50	2.24
Impacted	1	27-May-11	3.24	2.16
Impacted	1	27-May-11	4.64	4.19
Impacted	2	27-May-11	3.12	2.89
Impacted	2	27-May-11	3.37	2.60
Impacted	2	27-May-11	3.38	2.36
Impacted	3	27-May-11	3.05	2.04
Impacted	3	27-May-11	3.16	2.25
Impacted	3	27-May-11	3.57	2.37
Impacted	1	23-Sep-11	5.77	3.26
Impacted	1	23-Sep-11	6.19	3.01
Impacted	1	23-Sep-11	7.68	2.95
Impacted	2	23-Sep-11	4.42	2.37
Impacted	2	23-Sep-11	4.96	3.73
Impacted	2	23-Sep-11	6.24	3.39
Impacted	3	23-Sep-11	3.35	2.41
Impacted	3	23-Sep-11	5.42	3.66
Meadow	1	26-Sep-10	3.77	3.81
Meadow	1	26-Sep-10	4.32	3.29
Meadow	1	26-Sep-10	4.39	3.03
Meadow	2	26-Sep-10	3.49	2.76
Meadow	2	26-Sep-10	3.51	2.49
Meadow	2	26-Sep-10	3.91	2.86
Meadow	3	26-Sep-10	3.41	2.80
Meadow	3	26-Sep-10	4.25	3.30
Meadow	3	26-Sep-10	6.04	2.75
Meadow (East)	2	27-May-11	2.64	1.66
Meadow (East)	2	27-May-11	5.74	2.36
Meadow (East)	2	27-May-11		2.17
Meadow (East)	3	27-May-11	2.98	2.04
Meadow (East)	3	27-May-11	3.04	1.27
Meadow (East)	3	27-May-11	5.20	2.33
Meadow (East)	1	23-Sep-11	2.79	2.49
Meadow (East)	1	23-Sep-11	2.95	1.96
Meadow (East)	1	23-Sep-11	4.90	3.30
Meadow (East)	2	23-Sep-11	3.39	2.93
Meadow (East)	2	23-Sep-11	3.48	2.77
Meadow (East)	2	23-Sep-11	4.27	3.00
Meadow (East)	3	23-Sep-11	3.15	2.27
Meadow (East)	3	23-Sep-11	4.35	2.94
Meadow (East)	3	23-Sep-11	5.24	3.72

Site	Plot	Date Collected	Leached C (gC/m^2)	Leached N (gN/m^2)
Meadow (West)	1	27-May-11	1.82	0.90
Meadow (West)	1	27-May-11	1.98	1.06
Meadow (West)	1	27-May-11	3.31	1.60
Meadow (West)	2	27-May-11	3.35	1.67
Meadow (West)	2	27-May-11	3.62	1.93
Meadow (West)	2	27-May-11	3.74	1.91
Meadow (West)	3	27-May-11	1.51	0.89
Meadow (West)	3	27-May-11	1.62	1.09
Meadow (West)	3	27-May-11	1.68	1.02
Meadow (West)	1	23-Sep-11	3.50	2.62
Meadow (West)	2	23-Sep-11	3.99	3.44
Meadow (West)	2	23-Sep-11	4.05	2.90
Meadow (West)	2	23-Sep-11	4.18	3.03
Meadow (West)	3	23-Sep-11	2.64	2.09
Meadow (West)	3	23-Sep-11	2.83	2.30
Meadow (West)	3	23-Sep-11	4.03	3.13
Schist	1	1-May-10	2.89	0.56
Schist	1	1-May-10	3.26	0.73
Schist	1	1-May-10	5.83	0.76
Schist	2	1-May-10	2.75	0.67
Schist	2	1-May-10	3.01	0.56
Schist	2	1-May-10	3.92	1.12
Schist	3	1-May-10	3.00	0.72
Schist	3	1-May-10	3.36	0.68
Schist	3	1-May-10	3.39	0.69
Schist	4	1-May-10	2.98	0.59
Schist	4	1-May-10	3.45	0.49
Schist	4	1-May-10	4.02	0.84
Schist	1	12-Sep-10	2.98	2.26
Schist	1	12-Sep-10	3.16	2.47
Schist	1	12-Sep-10	4.38	3.39
Schist	2	12-Sep-10	3.84	2.80
Schist	2	12-Sep-10	4.07	2.90
Schist	2	12-Sep-10	4.92	2.36
Schist	3	12-Sep-10	3.26	2.54
Schist	3	12-Sep-10	3.43	2.59
Schist	3	12-Sep-10	6.72	2.84
Schist	4	12-Sep-10	3.61	2.18
Schist	4	12-Sep-10	3.77	2.37
Schist	4	12-Sep-10	9.23	4.18
Schist	5	12-Sep-10	2.83	2.33
Schist	5	12-Sep-10	3.21	2.25
Schist	5	12-Sep-10	3.52	2.65
Schist	1	19-May-11	3.25	2.87
Schist	1	19-May-11	3.42	2.24
Schist	1	19-May-11	3.64	3.20
Schist	2	19-May-11	3.37	2.54
Schist	2	19-May-11	3.82	3.61
Schist	2	19-May-11	4.20	3.17

Site	Plot	Date Collected	Leached C (gC/m^2)	Leached N (gN/m^2)
Schist	3	19-May-11	2.48	3.06
Schist	3	19-May-11	3.00	2.49
Schist	3	19-May-11	3.18	1.91
Schist	1	18-Sep-11	4.41	2.85
Schist	1	18-Sep-11	4.99	3.09
Schist	1	18-Sep-11	5.50	2.75
Schist	2	18-Sep-11	2.79	1.48
Schist	2	18-Sep-11	3.85	3.47
Schist	2	18-Sep-11	5.09	2.20
Schist	3	18-Sep-11	2.43	1.79
Schist	3	18-Sep-11	4.08	2.93
Schist	3	18-Sep-11	5.83	3.93

Table E.2. Gravimetric Soil Moisture, Extractable DOC and Extractable N Data

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Forest	1	2-Jul-10	23.24	29.63	1.65
Forest	1	2-Jul-10	23.02	30.74	1.88
Forest	1	2-Jul-10	17.43	38.97	3.28
Forest	2	2-Jul-10	17.33	18.53	1.50
Forest	2	2-Jul-10	20.05	24.89	1.89
Forest	2	2-Jul-10	27.64	34.01	2.53
Forest	3	2-Jul-10	23.46	35.49	2.46
Forest	3	2-Jul-10	15.16	53.08	4.85
Forest	3	2-Jul-10	19.39	74.36	4.78
Forest	1	26-Sep-10	31.35		
Forest	1	26-Sep-10	45.75	27.01	1.71
Forest	1	26-Sep-10	29.30	23.87	1.15
Forest	2	26-Sep-10	36.78	22.46	1.22
Forest	2	26-Sep-10	28.11	18.33	1.04
Forest	2	26-Sep-10	26.61	17.10	0.91
Forest	3	26-Sep-10	32.48		
Forest	3	26-Sep-10	52.50	66.63	3.56
Forest	3	26-Sep-10	34.66	59.42	3.12
Forest (West)	1	12-Feb-11	48.35	17.07	1.34
Forest (West)	1	12-Feb-11	64.85	19.95	1.97
Forest (West)	1	12-Feb-11	91.80	70.82	5.89
Forest (West)	2	12-Feb-11	31.07	8.93	0.74
Forest (West)	2	12-Feb-11	34.93	9.51	0.63
Forest (West)	2	12-Feb-11	34.64	11.59	0.91
Forest (West)	3	12-Feb-11	29.82	23.91	1.68
Forest (West)	3	12-Feb-11	42.75	121.03	6.65
Forest (West)	1	27-May-11	18.87	138.16	10.29
Forest (West)	1	27-May-11	35.60	227.77	17.29
Forest (West)	1	27-May-11	17.87	83.49	5.30
Forest (West)	2	27-May-11	10.42	74.57	4.94
Forest (West)	2	27-May-11	8.52	95.54	6.88
Forest (West)	2	27-May-11	8.37	40.87	2.93
Forest (West)	3	27-May-11	15.65	35.08	3.47
Forest (West)	3	27-May-11	18.39	122.47	8.62
Forest (West)	3	27-May-11	14.92	51.18	4.43
Forest (West)	1	22-Jul-11	17.50	55.27	6.40
Forest (West)	1	22-Jul-11	14.43	67.44	3.96
Forest (West)	1	22-Jul-11	41.76	80.38	5.15
Forest (West)	2	22-Jul-11	26.04	60.01	3.92
Forest (West)	2	22-Jul-11	36.80	98.49	7.62
Forest (West)	2	22-Jul-11	32.03	129.33	10.90
Forest (West)	3	22-Jul-11	32.56	44.87	4.89
Forest (West)	3	22-Jul-11	33.65	47.07	5.47
Forest (West)	3	22-Jul-11	56.76	55.20	6.30
Forest (West)	1	23-Sep-11	4.04	3.85	0.61
Forest (West)	1	23-Sep-11	7.39	67.52	2.88
Forest (West)	1	23-Sep-11	26.27	93.39	3.31

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Forest (West)	2	23-Sep-11	12.62	40.91	2.63
Forest (West)	2	23-Sep-11	10.21	72.37	3.80
Forest (West)	2	23-Sep-11	10.58	77.96	4.42
Forest (West)	3	23-Sep-11	13.27	27.52	1.73
Forest (West)	3	23-Sep-11	35.02	52.77	3.22
Forest (West)	3	23-Sep-11	12.03	70.57	3.97
Forest (East)	1	12-Feb-11		30.10	5.33
Forest (East)	1	12-Feb-11		39.76	6.57
Forest (East)	1	12-Feb-11		42.98	7.16
Forest (East)	2	12-Feb-11	50.34	17.96	2.46
Forest (East)	2	12-Feb-11	46.03	18.44	2.67
Forest (East)	2	12-Feb-11	61.61	21.23	3.01
Forest (East)	3	12-Feb-11	39.28	13.78	1.72
Forest (East)	3	12-Feb-11	62.21	22.65	2.19
Forest (East)	3	12-Feb-11		84.92	7.42
Forest (East)	1	27-May-11	47.14	11.33	1.83
Forest (East)	1	27-May-11	53.84	13.24	1.85
Forest (East)	1	27-May-11	61.29	13.58	1.97
Forest (East)	2	27-May-11	69.11	9.63	1.62
Forest (East)	2	27-May-11		19.53	3.08
Forest (East)	2	27-May-11		20.47	3.46
Forest (East)	3	27-May-11	27.82	4.54	0.53
Forest (East)	3	27-May-11	21.63	5.05	0.57
Forest (East)	3	27-May-11	24.85	4.43	0.44
Forest (East)	1	22-Jul-11	43.20	5.17	0.63
Forest (East)	1	22-Jul-11	40.90	10.32	2.12
Forest (East)	1	22-Jul-11	40.51	12.04	1.45
Forest (East)	2	22-Jul-11	42.28	7.23	1.11
Forest (East)	2	22-Jul-11	46.32	8.52	1.68
Forest (East)	2	22-Jul-11	40.15	11.40	1.89
Forest (East)	3	22-Jul-11	40.84	8.99	1.38
Forest (East)	3	22-Jul-11	57.08	9.47	1.84
Forest (East)	1	23-Sep-11	19.47	4.10	0.36
Forest (East)	1	23-Sep-11	13.22	3.66	0.31
Forest (East)	1	23-Sep-11	17.14	5.03	0.49
Forest (East)	2	23-Sep-11	40.19	7.44	0.57
Forest (East)	2	23-Sep-11	47.43	5.69	0.54
Forest (East)	2	23-Sep-11	41.83	7.26	0.62
Forest (East)	3	23-Sep-11	68.16	6.03	0.67
Forest (East)	3	23-Sep-11	90.43	10.05	0.91
Forest (East)	3	23-Sep-11	64.77	4.04	0.53
Granite	1	6-Mar-10	22.25	3.42	
Granite	1	6-Mar-10	23.77	4.17	
Granite	2	6-Mar-10	27.46	2.97	
Granite	2	6-Mar-10	27.68	4.25	
Granite	3	6-Mar-10	27.05	3.06	
Granite	3	6-Mar-10	22.21	3.24	
Granite	4	6-Mar-10	41.02	2.81	
Granite	4	6-Mar-10	29.18	2.85	

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Granite	1	1-May-10	46.08	3.26	
Granite	1	1-May-10	44.34	2.91	
Granite	1	1-May-10	47.82	2.67	
Granite	2	1-May-10	44.24	3.58	
Granite	2	1-May-10	44.54	0.96	
Granite	2	1-May-10	42.38	4.78	
Granite	3	1-May-10	44.49	4.13	
Granite	3	1-May-10	61.24	6.48	
Granite	3	1-May-10	41.85	7.25	
Granite	4	1-May-10	41.27	4.01	
Granite	4	1-May-10	52.97	5.51	
Granite	4	1-May-10	52.16	3.48	
Granite	1	27-Jun-10	3.56	6.70	
Granite	1	27-Jun-10	4.24	6.75	
Granite	1	27-Jun-10	3.51	9.32	
Granite	2	27-Jun-10	2.94	5.48	
Granite	2	27-Jun-10	2.65	5.63	
Granite	2	27-Jun-10	3.05	6.77	
Granite	3	27-Jun-10	1.89	6.22	
Granite	3	27-Jun-10	1.38	6.72	
Granite	3	27-Jun-10	1.96	7.86	
Granite	4	27-Jun-10	5.46	7.49	
Granite	4	27-Jun-10	5.35	9.53	
Granite	4	27-Jun-10	6.54	9.73	
Granite	5	27-Jun-10	3.50	3.47	
Granite	5	27-Jun-10	3.70	5.16	
Granite	5	27-Jun-10	4.09	5.85	
Granite	1	12-Sep-10	42.11	8.57	0.37
Granite	1	12-Sep-10	35.66	8.42	0.39
Granite	1	12-Sep-10	33.37	12.06	0.42
Granite	2	12-Sep-10	32.69	6.83	0.27
Granite	2	12-Sep-10	29.17	9.83	0.51
Granite	2	12-Sep-10	31.55	6.81	0.27
Granite	3	12-Sep-10	32.73	4.34	0.15
Granite	3	12-Sep-10	28.32	11.41	0.31
Granite	3	12-Sep-10	27.43	8.19	0.38
Granite	4	12-Sep-10	26.37	6.48	0.20
Granite	4	12-Sep-10	27.25	12.58	0.34
Granite	4	12-Sep-10	29.00	7.43	0.25
Granite	5	12-Sep-10	21.75	5.71	0.21
Granite	5	12-Sep-10	19.61	5.16	0.19
Granite	5	12-Sep-10	20.55	4.16	0.15
Granite	1	6-Feb-11	39.43	5.65	0.29
Granite	1	6-Feb-11	43.68	7.02	0.36
Granite	1	6-Feb-11	50.21	10.38	0.46
Granite	2	6-Feb-11	36.90	8.10	0.44
Granite	2	6-Feb-11	43.20	8.22	0.49
Granite	2	6-Feb-11	43.07	9.30	0.55
Granite	3	6-Feb-11	49.72	6.08	0.25

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Granite	3	6-Feb-11	29.06	6.82	0.31
Granite	3	6-Feb-11	34.68	7.04	0.30
Granite	1	19-May-11	4.29	8.51	0.34
Granite	1	19-May-11	3.51	6.45	0.24
Granite	1	19-May-11	4.63	16.47	0.33
Granite	2	19-May-11	2.88	13.58	0.41
Granite	2	19-May-11	8.20	10.25	0.32
Granite	2	19-May-11	3.38	12.13	0.38
Granite	3	19-May-11	11.24	5.75	0.16
Granite	3	19-May-11	7.04	6.92	0.26
Granite	3	19-May-11	9.93	6.95	0.19
Granite	1	22-Jul-11	3.66	17.09	0.72
Granite	1	22-Jul-11	4.17	18.04	0.78
Granite	1	22-Jul-11	3.46	18.71	0.98
Granite	2	22-Jul-11	2.74	8.32	0.36
Granite	2	22-Jul-11	2.16	9.64	0.40
Granite	2	22-Jul-11	2.78	18.22	0.57
Granite	3	22-Jul-11	2.46	4.76	0.20
Granite	3	22-Jul-11	3.16	9.56	0.46
Granite	3	22-Jul-11	3.09	9.64	0.40
Granite	1	18-Sep-11	17.19	3.36	0.08
Granite	1	18-Sep-11	11.44	3.39	0.07
Granite	1	18-Sep-11	17.28	4.49	0.08
Granite	1	18-Sep-11			
Granite	1	18-Sep-11			
Granite	1	18-Sep-11			
Granite	2	18-Sep-11			
Granite	2	18-Sep-11			
Granite	2	18-Sep-11	17.96	2.46	0.06
Granite	2	18-Sep-11	10.99	4.12	0.10
Granite	2	18-Sep-11	23.39	4.19	0.09
Granite	3	18-Sep-11			
Granite	3	18-Sep-11			
Granite	3	18-Sep-11			
Granite	3	18-Sep-11	24.39	2.07	0.05
Granite	3	18-Sep-11	22.85	2.87	0.07
Granite	3	18-Sep-11	23.69	3.15	0.09
Meadow	1	2-Jul-10	16.92	4.26	0.64
Meadow	1	2-Jul-10	16.59	5.48	0.82
Meadow	1	2-Jul-10	17.59	5.74	0.75
Meadow	2	2-Jul-10	20.38	4.27	0.53
Meadow	2	2-Jul-10	23.21	5.54	0.64
Meadow	2	2-Jul-10	26.05	7.37	0.80
Meadow	3	2-Jul-10	14.40	2.71	0.33
Meadow	3	2-Jul-10	14.16	3.08	0.32
Meadow	3	2-Jul-10	22.48	3.50	0.36
Meadow	1	26-Sep-10	46.27	4.48	0.37
Meadow	1	26-Sep-10	62.29	4.37	0.43
Meadow	1	26-Sep-10	52.29	4.73	0.40

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Meadow	2	26-Sep-10	55.80	4.11	0.48
Meadow	2	26-Sep-10	40.80	2.92	0.33
Meadow	2	26-Sep-10	39.96	4.22	0.34
Meadow	3	26-Sep-10	36.11	7.32	0.50
Meadow	3	26-Sep-10	34.60	7.96	0.60
Meadow	3	26-Sep-10	34.01	7.51	0.54
Meadow (West)	1	12-Feb-11	37.84	4.50	0.57
Meadow (West)	1	12-Feb-11	91.74	4.93	0.90
Meadow (West)	1	12-Feb-11	90.20	18.64	2.45
Meadow (West)	2	12-Feb-11	24.67	3.91	0.47
Meadow (West)	2	12-Feb-11	28.88	5.18	0.60
Meadow (West)	2	12-Feb-11	24.95	6.06	1.00
Meadow (West)	3	12-Feb-11	53.58	2.79	0.31
Meadow (West)	3	12-Feb-11	55.46	3.51	0.39
Meadow (West)	3	12-Feb-11	58.55	3.75	0.42
Meadow (West)	1	27-May-11	26.15	4.81	0.50
Meadow (West)	1	27-May-11	28.29	4.78	0.54
Meadow (West)	1	27-May-11	26.32	5.84	0.65
Meadow (West)	2	27-May-11	17.81	3.46	0.32
Meadow (West)	2	27-May-11	16.34	2.20	0.25
Meadow (West)	2	27-May-11	16.68	3.03	0.39
Meadow (West)	3	27-May-11	37.87	9.76	0.99
Meadow (West)	3	27-May-11	34.87	10.24	1.22
Meadow (West)	3	27-May-11	33.22	9.55	1.05
Meadow (West)	1	22-Jul-11	15.60	6.36	1.23
Meadow (West)	1	22-Jul-11	14.95	7.96	1.27
Meadow (West)	1	22-Jul-11	21.21	13.99	2.35
Meadow (West)	2	22-Jul-11	19.28	1.54	0.23
Meadow (West)	2	22-Jul-11	22.89	3.59	0.55
Meadow (West)	2	22-Jul-11	23.07	4.20	0.67
Meadow (West)	3	22-Jul-11	29.60	3.21	0.49
Meadow (West)	3	22-Jul-11		3.67	0.51
Meadow (West)	3	22-Jul-11	32.90	11.43	1.93
Meadow (West)	1	23-Sep-11	15.21	1.67	0.18
Meadow (West)	1	23-Sep-11	19.61	1.66	0.24
Meadow (West)	1	23-Sep-11	32.48	2.04	0.35
Meadow (West)	2	23-Sep-11	39.92	4.19	0.42
Meadow (West)	2	23-Sep-11	23.32	6.56	0.54
Meadow (West)	2	23-Sep-11	44.60	1.94	0.20
Meadow (West)	3	23-Sep-11	27.67	1.71	0.22
Meadow (West)	3	23-Sep-11	29.37	1.60	0.19
Meadow (West)	3	23-Sep-11	30.36	1.77	0.19
Meadow (East)	1	12-Feb-11	61.46	7.44	0.84
Meadow (East)	1	12-Feb-11	66.44	13.77	1.52
Meadow (East)	2	12-Feb-11	49.61	10.61	1.50
Meadow (East)	2	12-Feb-11	46.23	11.68	1.59
Meadow (East)	2	12-Feb-11	56.48	14.12	1.80
Meadow (East)	3	12-Feb-11	64.48	15.30	1.88
Meadow (East)	3	12-Feb-11	68.30	15.63	2.01

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Meadow (East)	3	12-Feb-11	69.73	21.64	2.29
Meadow (East)	1	27-May-11	30.57	13.57	1.83
Meadow (East)	1	27-May-11	29.86	14.31	1.94
Meadow (East)	1	27-May-11	28.44	14.69	2.02
Meadow (East)	2	27-May-11	27.94	15.86	1.87
Meadow (East)	2	27-May-11	31.56	21.44	2.51
Meadow (East)	2	27-May-11	27.18	16.80	1.99
Meadow (East)	3	27-May-11	31.48	13.54	1.82
Meadow (East)	3	27-May-11	32.57	10.96	1.42
Meadow (East)	3	27-May-11	30.11	8.42	1.07
Meadow (East)	1	22-Jul-11	40.24	51.79	4.63
Meadow (East)	1	22-Jul-11	39.04	81.84	7.07
Meadow (East)	1	22-Jul-11	30.16	91.79	8.50
Meadow (East)	2	22-Jul-11	31.95	5.37	1.38
Meadow (East)	2	22-Jul-11		7.00	1.25
Meadow (East)	2	22-Jul-11	34.29	12.73	1.77
Meadow (East)	3	22-Jul-11	22.87	8.77	1.12
Meadow (East)	3	22-Jul-11	25.48	21.17	3.04
Meadow (East)	3	22-Jul-11	23.74	24.01	3.01
Meadow (East)	1	23-Sep-11	23.91	11.87	1.48
Meadow (East)	1	23-Sep-11	28.30	7.93	0.96
Meadow (East)	1	23-Sep-11	25.83	13.05	0.62
Meadow (East)	2	23-Sep-11	34.51	5.45	0.95
Meadow (East)	2	23-Sep-11	32.96	8.69	1.23
Meadow (East)	2	23-Sep-11	34.30	6.98	1.34
Meadow (East)	3	23-Sep-11	30.23	2.73	0.35
Meadow (East)	3	23-Sep-11	31.05	3.56	0.47
Meadow (East)	3	23-Sep-11	32.13	1.97	0.39
Impacted	1	26-May-10			
Impacted	1	26-May-10			
Impacted	2	26-May-10			
Impacted	2	26-May-10			
Impacted	2	26-May-10			
Impacted	3	26-May-10			
Impacted	3	26-May-10			
Impacted	3	26-May-10			
Impacted	1	2-Jul-10	16.08	18.92	2.66
Impacted	1	2-Jul-10	16.56	30.11	3.35
Impacted	1	2-Jul-10	70.49	82.75	10.23
Impacted	2	2-Jul-10	14.04	16.27	0.99
Impacted	2	2-Jul-10	28.53	18.31	1.23
Impacted	2	2-Jul-10	15.00	18.66	1.09
Impacted	3	2-Jul-10	19.64	43.29	3.34
Impacted	3	2-Jul-10	19.23	57.46	4.77
Impacted	3	2-Jul-10	31.55	191.32	4.52
Impacted	1	26-Sep-10	52.94	154.35	10.54
Impacted	1	26-Sep-10	50.81	193.61	15.29
Impacted	1	26-Sep-10	18.62	126.83	7.72
Impacted	2	26-Sep-10	38.11	40.05	2.61

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Impacted	2	26-Sep-10	42.70	31.34	2.27
Impacted	2	26-Sep-10	40.06	17.45	1.10
Impacted	3	26-Sep-10	42.44	185.00	10.50
Impacted	3	26-Sep-10	26.97	161.56	8.73
Impacted	3	26-Sep-10	45.52	187.69	12.24
Impacted	1	12-Feb-11	12.56	31.10	4.65
Impacted	1	12-Feb-11	17.52	62.49	7.89
Impacted	1	12-Feb-11	22.63	95.45	10.49
Impacted	2	12-Feb-11	51.79	47.29	5.70
Impacted	2	12-Feb-11	58.08	56.68	6.93
Impacted	2	12-Feb-11	65.37	60.32	7.28
Impacted	3	12-Feb-11	41.00	55.37	7.20
Impacted	3	12-Feb-11	67.84	84.77	13.41
Impacted	3	12-Feb-11	55.20	134.62	19.29
Impacted	1	27-May-11	35.76	49.04	4.55
Impacted	1	27-May-11	53.93	40.18	4.29
Impacted	1	27-May-11	42.15	61.52	5.96
Impacted	2	27-May-11	70.02	92.35	6.73
Impacted	2	27-May-11	76.22	258.17	16.44
Impacted	2	27-May-11	59.74	136.08	11.45
Impacted	3	27-May-11	39.34	60.01	5.22
Impacted	3	27-May-11	23.73	47.99	3.75
Impacted	3	27-May-11	31.37	46.17	4.50
Impacted	1	22-Jul-11	12.06	51.25	4.91
Impacted	1	22-Jul-11	14.55	71.67	6.48
Impacted	1	22-Jul-11	13.14	105.99	10.65
Impacted	2	22-Jul-11	18.65	31.65	3.27
Impacted	2	22-Jul-11	32.80	99.35	10.82
Impacted	2	22-Jul-11	22.15	154.35	11.18
Impacted	3	22-Jul-11	31.21	149.57	13.71
Impacted	3	22-Jul-11	25.12	161.11	13.47
Impacted	3	22-Jul-11	27.72	204.98	18.43
Impacted	1	23-Sep-11	12.23	22.23	2.31
Impacted	1	23-Sep-11	19.14	16.82	1.78
Impacted	1	23-Sep-11	19.17	18.88	1.72
Impacted	2	23-Sep-11	29.35	35.57	2.29
Impacted	2	23-Sep-11	33.54	4.69	0.82
Impacted	2	23-Sep-11	33.11	30.12	2.88
Impacted	3	23-Sep-11	32.67	4.41	0.64
Impacted	3	23-Sep-11	23.10	2.11	0.30
Schist	1	6-Mar-10	37.12	2.69	
Schist	1	6-Mar-10	38.84	2.95	
Schist	1	6-Mar-10	37.91	3.13	
Schist	2	6-Mar-10	27.65	4.60	
Schist	2	6-Mar-10	31.39	6.15	
Schist	2	6-Mar-10	28.68	6.48	
Schist	3	6-Mar-10	41.27	1.50	
Schist	3	6-Mar-10	33.22	2.71	
Schist	3	6-Mar-10	33.02	4.66	

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Schist	4	6-Mar-10	37.62	1.86	
Schist	4	6-Mar-10	39.31	2.01	
Schist	4	6-Mar-10	45.41	2.15	
Schist	1	1-May-10	76.09	4.79	
Schist	1	1-May-10	83.94	4.79	
Schist	1	1-May-10	76.76	5.09	
Schist	2	1-May-10	51.13	3.25	
Schist	2	1-May-10	60.72	6.72	
Schist	2	1-May-10	54.36	3.58	
Schist	3	1-May-10	70.40	3.62	
Schist	3	1-May-10	53.32	4.65	
Schist	3	1-May-10	59.55	4.62	
Schist	4	1-May-10	54.94	3.59	
Schist	4	1-May-10	71.30	3.76	
Schist	4	1-May-10	88.50	3.68	
Schist	1	27-Jun-10	10.93	8.08	
Schist	1	27-Jun-10	7.66	8.50	
Schist	1	27-Jun-10	10.91	10.81	
Schist	2	27-Jun-10	8.29	5.03	
Schist	2	27-Jun-10	7.17	5.23	
Schist	2	27-Jun-10	8.12	5.50	
Schist	3	27-Jun-10	3.83	8.84	
Schist	3	27-Jun-10	4.86	8.85	
Schist	3	27-Jun-10	4.55	9.14	
Schist	4	27-Jun-10	4.22	8.32	
Schist	4	27-Jun-10	5.15	8.86	
Schist	4	27-Jun-10	4.31	15.10	
Schist	5	27-Jun-10	13.46	6.55	
Schist	5	27-Jun-10	10.75	8.14	
Schist	5	27-Jun-10	9.04	8.77	
Schist	1	12-Sep-10			
Schist	1	12-Sep-10	61.15	9.36	0.29
Schist	1	12-Sep-10	45.76	10.97	0.40
Schist	2	12-Sep-10	45.97	13.03	0.28
Schist	2	12-Sep-10	44.01	14.70	0.32
Schist	2	12-Sep-10	41.04	10.23	0.19
Schist	3	12-Sep-10	26.12	6.95	0.15
Schist	3	12-Sep-10	35.39	12.74	0.28
Schist	3	12-Sep-10	38.50	7.83	0.16
Schist	4	12-Sep-10	35.18	17.45	0.37
Schist	4	12-Sep-10	37.07	18.75	0.37
Schist	4	12-Sep-10	37.50	13.10	0.23
Schist	5	12-Sep-10	56.92	10.02	0.22
Schist	5	12-Sep-10	60.58	23.55	0.60
Schist	5	12-Sep-10	54.60	14.81	0.25
Schist	1	6-Feb-11	39.48	10.11	0.29
Schist	1	6-Feb-11	40.06	11.09	0.29
Schist	1	6-Feb-11	37.24	13.13	0.37
Schist	2	6-Feb-11	35.84	11.15	0.30

Site	Plot	Date Collected	Soil Moisture (%)	Extractable C (g/m^2)	Extractable N (g/m^2)
Schist	2	6-Feb-11	43.36	12.80	0.36
Schist	2	6-Feb-11	52.51	13.31	0.38
Schist	3	6-Feb-11	60.36	10.93	0.29
Schist	3	6-Feb-11	64.45	14.97	0.42
Schist	3	6-Feb-11	67.51	18.03	0.53
Schist	1	19-May-11	7.20	5.65	0.13
Schist	1	19-May-11	7.80	5.03	0.10
Schist	1	19-May-11	9.63	5.83	0.12
Schist	2	19-May-11	19.60	7.97	0.14
Schist	2	19-May-11	16.55	7.87	0.13
Schist	2	19-May-11	16.09	7.05	0.13
Schist	3	19-May-11	8.10	8.24	0.16
Schist	3	19-May-11	5.04	1.80	0.04
Schist	3	19-May-11	6.83	7.81	0.16
Schist	1	22-Jul-11	3.78	13.86	0.50
Schist	1	22-Jul-11	4.42	16.90	0.49
Schist	1	22-Jul-11	4.61	17.11	0.45
Schist	2	22-Jul-11	2.94	10.76	0.31
Schist	2	22-Jul-11	3.45	18.29	0.44
Schist	2	22-Jul-11	3.27	21.79	0.50
Schist	3	22-Jul-11	2.66	13.20	0.20
Schist	3	22-Jul-11	1.87	13.53	0.26
Schist	3	22-Jul-11	2.16	17.61	0.31
Schist	1	18-Sep-11	25.93	2.14	0.05
Schist	1	18-Sep-11	22.38	2.42	0.15
Schist	1	18-Sep-11	25.14	2.71	0.08
Schist	2	18-Sep-11	14.09	1.41	0.02
Schist	2	18-Sep-11	17.35	2.86	0.03
Schist	2	18-Sep-11	17.61	2.97	0.04
Schist	3	18-Sep-11	18.46	1.43	0.02
Schist	3	18-Sep-11	24.78	1.84	0.02
Schist	3	18-Sep-11	19.67	2.49	0.03

Table G.

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Forest	1	15-Mar-10	0.52
Forest	1	15-Mar-10	0.55
Forest	1	15-Mar-10	0.49
Forest	1	15-Mar-10	0.48
Forest	1	15-Mar-10	0.47
Forest	1	29-Mar-10	0.28
Forest	1	29-Mar-10	0.26
Forest	2	29-Mar-10	0.28
Forest	2	29-Mar-10	0.23
Forest	2	29-Mar-10	0.19
Forest	2	29-Mar-10	0.2
Forest	2	29-Mar-10	0.24
Forest	2	29-Mar-10	0.55
Forest	2	29-Mar-10	0.21
Forest	3	29-Mar-10	0.21
Forest	3	29-Mar-10	0.32
Forest	3	29-Mar-10	0.34
Forest	3	29-Mar-10	0.4
Forest	3	29-Mar-10	0.37
Forest	3	29-Mar-10	0.37
Forest	3	29-Mar-10	0.37
Forest	1	2-Jul-10	2.23
Forest	1	2-Jul-10	1.31
Forest	1	2-Jul-10	1.83
Forest	1	2-Jul-10	1.77
Forest	1	2-Jul-10	0.98
Forest	2	2-Jul-10	0
Forest	2	2-Jul-10	0.33
Forest	2	2-Jul-10	0
Forest	2	2-Jul-10	0
Forest	2	2-Jul-10	0.13
Forest	3	2-Jul-10	1.96
Forest	3	2-Jul-10	3.86
Forest	3	2-Jul-10	0
Forest	3	2-Jul-10	1.64
Forest	3	2-Jul-10	6.61
Forest	1	31-Jul-10	5.7
Forest	1	31-Jul-10	5.96
Forest	1	31-Jul-10	4.52
Forest	1	31-Jul-10	4.06
Forest	1	31-Jul-10	3.93
Forest	2	31-Jul-10	4.65
Forest	2	31-Jul-10	2.75
Forest	2	31-Jul-10	0.59
Forest	2	31-Jul-10	2.95
Forest	2	31-Jul-10	3.54
Forest	3	31-Jul-10	5.04
Forest	3	31-Jul-10	4.85
Forest	3	31-Jul-10	10.54
Forest	3	31-Jul-10	11.99
Forest	3	31-Jul-10	5.76
Forest	3	31-Jul-10	7.47
Forest	1	26-Sep-10	1.51
Forest	1	26-Sep-10	1.9
Forest	1	26-Sep-10	1.18
Forest	1	26-Sep-10	1.64
Forest	1	26-Sep-10	1.24
Forest	1	26-Sep-10	0.65
Forest	1	26-Sep-10	2.42
Forest	2	26-Sep-10	2.23
Forest	2	26-Sep-10	2.55
Forest	2	26-Sep-10	2.16
Forest	2	26-Sep-10	0
Forest	2	26-Sep-10	3.01
Forest	2	26-Sep-10	2.23
Forest	3	26-Sep-10	3.67
Forest	3	26-Sep-10	0
Forest	3	26-Sep-10	2.29
Forest	3	26-Sep-10	1.9
Forest	3	26-Sep-10	0.72
Forest	3	26-Sep-10	5.63
Forest	3	26-Sep-10	1.96
Forest (east)	1	12-Feb-11	2.46
Forest (east)	1	12-Feb-11	3.61
Forest (east)	1	12-Feb-11	2.36
Forest (east)	1	12-Feb-11	3.16
Forest (east)	2	12-Feb-11	3.45
Forest (east)	2	12-Feb-11	4.99
Forest (east)	2	12-Feb-11	3.86
Forest (east)	2	12-Feb-11	3.35
Forest (east)	3	12-Feb-11	2.71
Forest (east)	3	12-Feb-11	2.29
Forest (east)	3	12-Feb-11	2.56
Forest (east)	3	12-Feb-11	2.04
Forest (east)	1	12-Mar-11	0.1
Forest (east)	1	12-Mar-11	0.14
Forest (east)	1	12-Mar-11	0.09
Forest (east)	1	12-Mar-11	0.13
Forest (east)	2	12-Mar-11	0.14
Forest (east)	2	12-Mar-11	0.2
Forest (east)	2	12-Mar-11	0.15
Forest (east)	2	12-Mar-11	0.13

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Forest (east)	3	12-Mar-11	0.11
Forest (east)	3	12-Mar-11	0.09
Forest (east)	3	12-Mar-11	0.1
Forest (east)	3	12-Mar-11	0.09
Forest (east)	1	27-May-11	0.33
Forest (east)	1	27-May-11	0
Forest (east)	1	27-May-11	0.65
Forest (east)	1	27-May-11	0
Forest (east)	1	27-May-11	4
Forest (east)	2	27-May-11	1.05
Forest (east)	2	27-May-11	0.79
Forest (east)	2	27-May-11	1.44
Forest (east)	2	27-May-11	2.62
Forest (east)	2	27-May-11	0.07
Forest (east)	3	27-May-11	1.96
Forest (east)	3	27-May-11	0.52
Forest (east)	3	27-May-11	0.2
Forest (east)	3	27-May-11	0.72
Forest (east)	3	27-May-11	0
Forest (east)	1	22-Jul-11	6.09
Forest (east)	1	22-Jul-11	1.51
Forest (east)	1	22-Jul-11	5.7
Forest (east)	1	22-Jul-11	5.57
Forest (east)	1	22-Jul-11	1.9
Forest (east)	2	22-Jul-11	0.52
Forest (east)	2	22-Jul-11	2.55
Forest (east)	2	22-Jul-11	3.73
Forest (east)	2	22-Jul-11	3.14
Forest (east)	2	22-Jul-11	2.36
Forest (east)	3	22-Jul-11	7.34
Forest (east)	3	22-Jul-11	4.85
Forest (east)	3	22-Jul-11	5.44
Forest (east)	3	22-Jul-11	7.14
Forest (east)	3	22-Jul-11	4.26
Forest (east)	1	10-Aug-11	2.16
Forest (east)	1	10-Aug-11	2.55
Forest (east)	1	10-Aug-11	3.8
Forest (east)	1	10-Aug-11	4.39
Forest (east)	1	10-Aug-11	0
Forest (east)	2	10-Aug-11	4.91
Forest (east)	2	10-Aug-11	2.36
Forest (east)	2	10-Aug-11	4.45
Forest (east)	2	10-Aug-11	0.46
Forest (east)	2	10-Aug-11	2.03
Forest (east)	3	10-Aug-11	5.44
Forest (east)	3	10-Aug-11	3.01
Forest (east)	3	10-Aug-11	6.81
Forest (east)	3	10-Aug-11	7.14

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Forest (east)	3	10-Aug-11	3.93
Forest (east)	1	23-Sep-11	0.33
Forest (east)	1	23-Sep-11	2.55
Forest (east)	1	23-Sep-11	4.19
Forest (east)	1	23-Sep-11	0.98
Forest (east)	1	23-Sep-11	1.38
Forest (east)	2	23-Sep-11	4.98
Forest (east)	2	23-Sep-11	2.23
Forest (east)	2	23-Sep-11	0
Forest (east)	2	23-Sep-11	0
Forest (east)	2	23-Sep-11	0
Forest (east)	2	23-Sep-11	0.72
Forest (east)	2	23-Sep-11	4.45
Forest (east)	3	23-Sep-11	2.95
Forest (east)	3	23-Sep-11	6.35
Forest (east)	3	23-Sep-11	5.17
Forest (east)	3	23-Sep-11	0
Forest (east)	3	23-Sep-11	8.45
Forest (west)	1	12-Feb-11	2.28
Forest (west)	1	12-Feb-11	2.56
Forest (west)	1	12-Feb-11	2.15
Forest (west)	1	12-Feb-11	2.68
Forest (west)	2	12-Feb-11	1.4
Forest (west)	2	12-Feb-11	1.26
Forest (west)	2	12-Feb-11	1.27
Forest (west)	2	12-Feb-11	1.53
Forest (west)	3	12-Feb-11	0.73
Forest (west)	3	12-Feb-11	1.67
Forest (west)	3	12-Feb-11	1.63
Forest (west)	3	12-Feb-11	1.41
Forest (west)	3	12-Feb-11	2.2
Forest (west)	1	12-Mar-11	0.09
Forest (west)	1	12-Mar-11	0.1
Forest (west)	1	12-Mar-11	0.09
Forest (west)	1	12-Mar-11	0.11
Forest (west)	2	12-Mar-11	0.06
Forest (west)	2	12-Mar-11	0.05
Forest (west)	2	12-Mar-11	0.05
Forest (west)	2	12-Mar-11	0.06
Forest (west)	3	12-Mar-11	0.03
Forest (west)	3	12-Mar-11	0.07
Forest (west)	3	12-Mar-11	0.07
Forest (west)	3	12-Mar-11	0.06
Forest (west)	3	12-Mar-11	0.09
Forest (west)	1	14-Apr-11	0.2
Forest (west)	1	14-Apr-11	0.2
Forest (west)	1	14-Apr-11	0
Forest (west)	1	14-Apr-11	0.2

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Forest (west)	2	14-Apr-11	0
Forest (west)	2	14-Apr-11	0.07
Forest (west)	2	14-Apr-11	0
Forest (west)	2	14-Apr-11	0
Forest (west)	1	27-May-11	0.13
Forest (west)	1	27-May-11	0.39
Forest (west)	1	27-May-11	0.33
Forest (west)	1	27-May-11	0.46
Forest (west)	1	27-May-11	0.39
Forest (west)	2	27-May-11	0.59
Forest (west)	2	27-May-11	0.2
Forest (west)	2	27-May-11	0.46
Forest (west)	2	27-May-11	0.46
Forest (west)	2	27-May-11	0
Forest (west)	3	27-May-11	0.85
Forest (west)	3	27-May-11	0
Forest (west)	3	27-May-11	0.59
Forest (west)	3	27-May-11	0.13
Forest (west)	3	27-May-11	0
Forest (west)	1	22-Jul-11	5.37
Forest (west)	1	22-Jul-11	5.83
Forest (west)	1	22-Jul-11	4.65
Forest (west)	1	22-Jul-11	3.86
Forest (west)	1	22-Jul-11	5.11
Forest (west)	2	22-Jul-11	1.31
Forest (west)	2	22-Jul-11	3.21
Forest (west)	2	22-Jul-11	1.83
Forest (west)	2	22-Jul-11	1.96
Forest (west)	2	22-Jul-11	3.41
Forest (west)	3	22-Jul-11	0
Forest (west)	3	22-Jul-11	0.2
Forest (west)	3	22-Jul-11	1.96
Forest (west)	3	22-Jul-11	0.72
Forest (west)	3	22-Jul-11	1.31
Forest (west)	1	10-Aug-11	6.29
Forest (west)	1	10-Aug-11	5.76
Forest (west)	1	10-Aug-11	2.82
Forest (west)	1	10-Aug-11	0.72
Forest (west)	1	10-Aug-11	8.19
Forest (west)	2	10-Aug-11	2.75
Forest (west)	2	10-Aug-11	0.59
Forest (west)	2	10-Aug-11	5.37
Forest (west)	2	10-Aug-11	1.77
Forest (west)	2	10-Aug-11	5.5
Forest (west)	3	10-Aug-11	1.96
Forest (west)	3	10-Aug-11	0.46
Forest (west)	3	10-Aug-11	5.63
Forest (west)	3	10-Aug-11	0

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Forest (west)	3	10-Aug-11	4.45
Forest (west)	1	23-Sep-11	9.1
Forest (west)	1	23-Sep-11	2.23
Forest (west)	1	23-Sep-11	0.65
Forest (west)	1	23-Sep-11	5.31
Forest (west)	1	23-Sep-11	2.42
Forest (west)	2	23-Sep-11	2.16
Forest (west)	2	23-Sep-11	1.11
Forest (west)	2	23-Sep-11	0.59
Forest (west)	2	23-Sep-11	0.52
Forest (west)	2	23-Sep-11	0.72
Forest (west)	3	23-Sep-11	1.64
Forest (west)	3	23-Sep-11	0.59
Forest (west)	3	23-Sep-11	1.44
Forest (west)	3	23-Sep-11	0.2
Forest (west)	3	23-Sep-11	0.92
Granite	1	6-Mar-10	0.5
Granite	1	6-Mar-10	0.87
Granite	1	6-Mar-10	0.5
Granite	1	6-Mar-10	0.52
Granite	1	6-Mar-10	0.37
Granite	1	6-Mar-10	0.37
Granite	1	6-Mar-10	0.37
Granite	1	6-Mar-10	0.35
Granite	1	6-Mar-10	0.37
Granite	2	6-Mar-10	0.85
Granite	2	6-Mar-10	0.51
Granite	2	6-Mar-10	0.88
Granite	2	6-Mar-10	0.29
Granite	2	6-Mar-10	0.28
Granite	2	6-Mar-10	0.29
Granite	2	6-Mar-10	0.25
Granite	2	6-Mar-10	0.31
Granite	3	6-Mar-10	0.54
Granite	3	6-Mar-10	0.53
Granite	3	6-Mar-10	0.94
Granite	3	6-Mar-10	0.74
Granite	3	6-Mar-10	0.3
Granite	3	6-Mar-10	0.23
Granite	3	6-Mar-10	0.24
Granite	3	6-Mar-10	0.25
Granite	3	6-Mar-10	0.25
Granite	4	6-Mar-10	0.28
Granite	4	6-Mar-10	0.27
Granite	4	6-Mar-10	0.23
Granite	4	6-Mar-10	0.22
Granite	4	6-Mar-10	0.26
Granite	1	22-Mar-10	0.43

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Granite	1	22-Mar-10	0.39
Granite	1	22-Mar-10	0.31
Granite	1	22-Mar-10	0.23
Granite	1	22-Mar-10	0.48
Granite	1	22-Mar-10	0.64
Granite	2	22-Mar-10	0.52
Granite	2	22-Mar-10	0.62
Granite	2	22-Mar-10	0.57
Granite	2	22-Mar-10	0.69
Granite	2	22-Mar-10	0.38
Granite	2	22-Mar-10	0.42
Granite	3	22-Mar-10	0.49
Granite	3	22-Mar-10	0.35
Granite	3	22-Mar-10	0.46
Granite	3	22-Mar-10	0.51
Granite	3	22-Mar-10	0.59
Granite	3	22-Mar-10	0.65
Granite	4	22-Mar-10	0.66
Granite	4	22-Mar-10	0.67
Granite	4	22-Mar-10	0.59
Granite	4	22-Mar-10	0.65
Granite	4	22-Mar-10	0.66
Granite	4	22-Mar-10	0.67
Granite	1	29-Jun-10	0
Granite	1	29-Jun-10	0
Granite	1	29-Jun-10	0.65
Granite	1	29-Jun-10	0.26
Granite	1	29-Jun-10	0.46
Granite	1	29-Jun-10	0.1
Granite	2	29-Jun-10	0.26
Granite	2	29-Jun-10	0.07
Granite	2	29-Jun-10	0
Granite	2	29-Jun-10	0.13
Granite	2	29-Jun-10	0.2
Granite	3	29-Jun-10	3.27
Granite	3	29-Jun-10	3.8
Granite	3	29-Jun-10	1.44
Granite	3	29-Jun-10	0.92
Granite	3	29-Jun-10	0.72
Granite	4	29-Jun-10	0.33
Granite	4	29-Jun-10	1.24
Granite	4	29-Jun-10	1.57
Granite	4	29-Jun-10	2.88
Granite	4	29-Jun-10	1.11
Granite	5	29-Jun-10	1.18
Granite	5	29-Jun-10	0
Granite	5	29-Jun-10	0.85
Granite	5	29-Jun-10	0.72
Granite	5	29-Jun-10	0.26
Granite	5	29-Jun-10	0.2
Granite	1	15-Jul-10	7.6
Granite	1	15-Jul-10	4.85
Granite	1	15-Jul-10	6.22
Granite	1	15-Jul-10	2.29
Granite	1	15-Jul-10	3.54
Granite	2	15-Jul-10	0
Granite	2	15-Jul-10	0.39
Granite	2	15-Jul-10	0
Granite	2	15-Jul-10	1.44
Granite	2	15-Jul-10	1.44
Granite	3	15-Jul-10	3.14
Granite	3	15-Jul-10	2.69
Granite	3	15-Jul-10	3.14
Granite	3	15-Jul-10	3.27
Granite	3	15-Jul-10	0.98
Granite	4	15-Jul-10	2.75
Granite	4	15-Jul-10	3.93
Granite	4	15-Jul-10	5.76
Granite	4	15-Jul-10	7.73
Granite	4	15-Jul-10	5.63
Granite	5	15-Jul-10	1.18
Granite	5	15-Jul-10	1.51
Granite	5	15-Jul-10	0.72
Granite	5	15-Jul-10	0.72
Granite	5	15-Jul-10	1.57
Granite	1	28-Jul-10	0.26
Granite	1	28-Jul-10	1.18
Granite	1	28-Jul-10	2.23
Granite	1	28-Jul-10	1.38
Granite	1	28-Jul-10	1.31
Granite	2	28-Jul-10	0.39
Granite	2	28-Jul-10	0.92
Granite	2	28-Jul-10	0
Granite	2	28-Jul-10	2.95
Granite	2	28-Jul-10	0
Granite	3	28-Jul-10	3.6
Granite	3	28-Jul-10	0
Granite	3	28-Jul-10	0.13
Granite	3	28-Jul-10	4.26
Granite	3	28-Jul-10	1.96
Granite	1	12-Sep-10	0.52
Granite	1	12-Sep-10	2.62
Granite	1	12-Sep-10	2.42
Granite	1	12-Sep-10	0
Granite	1	12-Sep-10	2.16
Granite	1	12-Sep-10	0

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Granite	2	12-Sep-10	2.95
Granite	2	12-Sep-10	3.86
Granite	2	12-Sep-10	2.23
Granite	2	12-Sep-10	2.82
Granite	2	12-Sep-10	2.75
Granite	3	12-Sep-10	2.75
Granite	3	12-Sep-10	2.1
Granite	3	12-Sep-10	3.21
Granite	3	12-Sep-10	3.08
Granite	3	12-Sep-10	1.83
Granite	4	12-Sep-10	0
Granite	4	12-Sep-10	2.82
Granite	4	12-Sep-10	0
Granite	4	12-Sep-10	0.92
Granite	4	12-Sep-10	0.46
Granite	4	12-Sep-10	0.72
Granite	5	12-Sep-10	5.63
Granite	5	12-Sep-10	1.83
Granite	5	12-Sep-10	5.11
Granite	5	12-Sep-10	3.8
Granite	5	12-Sep-10	4
Granite	1	6-Feb-11	0
Granite	1	6-Feb-11	0
Granite	1	6-Feb-11	0
Granite	1	6-Feb-11	0
Granite	1	6-Feb-11	0
Granite	1	6-Feb-11	0
Granite	2	6-Feb-11	0
Granite	2	6-Feb-11	0
Granite	2	6-Feb-11	0
Granite	2	6-Feb-11	0
Granite	2	6-Feb-11	0
Granite	3	6-Feb-11	0
Granite	3	6-Feb-11	0
Granite	3	6-Feb-11	0
Granite	3	6-Feb-11	0
Granite	3	6-Feb-11	0
Granite	1	7-Mar-11	0
Granite	1	7-Mar-11	0.26
Granite	1	7-Mar-11	0.26
Granite	1	7-Mar-11	0.52
Granite	1	7-Mar-11	0.33
Granite	2	7-Mar-11	0.07
Granite	2	7-Mar-11	0
Granite	2	7-Mar-11	0
Granite	2	7-Mar-11	0
Granite	2	7-Mar-11	0
Granite	3	7-Mar-11	0
Granite	3	7-Mar-11	0
Granite	3	7-Mar-11	0
Granite	3	7-Mar-11	0.2
Granite	3	7-Mar-11	0
Granite	1	11-Apr-11	0.98
Granite	1	11-Apr-11	0.92
Granite	1	11-Apr-11	0.72
Granite	1	11-Apr-11	0.46
Granite	1	11-Apr-11	0.59
Granite	2	11-Apr-11	0.59
Granite	2	11-Apr-11	0.26
Granite	2	11-Apr-11	0.33
Granite	2	11-Apr-11	0.39
Granite	2	11-Apr-11	0.46
Granite	3	11-Apr-11	0.72
Granite	3	11-Apr-11	0.72
Granite	3	11-Apr-11	0.46
Granite	3	11-Apr-11	0.79
Granite	3	11-Apr-11	1.18
Granite	1	19-May-11	0.13
Granite	1	19-May-11	0
Granite	1	19-May-11	0.13
Granite	1	19-May-11	0.79
Granite	1	19-May-11	0.33
Granite	2	19-May-11	0
Granite	2	19-May-11	0
Granite	2	19-May-11	0.39
Granite	2	19-May-11	0
Granite	2	19-May-11	0
Granite	3	19-May-11	0.26
Granite	3	19-May-11	0
Granite	3	19-May-11	0
Granite	3	19-May-11	0
Granite	3	19-May-11	0
Granite	1	22-Jun-11	0.59
Granite	1	22-Jun-11	0.13
Granite	1	22-Jun-11	0.92
Granite	1	22-Jun-11	0.39
Granite	1	22-Jun-11	0.2
Granite	2	22-Jun-11	0
Granite	2	22-Jun-11	0.26
Granite	2	22-Jun-11	0
Granite	2	22-Jun-11	0
Granite	2	22-Jun-11	0.2
Granite	3	22-Jun-11	0.92
Granite	3	22-Jun-11	0.33
Granite	3	22-Jun-11	0
Granite	3	22-Jun-11	0

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Granite	3	22-Jun-11	0.26
Granite	1	28-Aug-11	0
Granite	1	28-Aug-11	4.32
Granite	1	28-Aug-11	0
Granite	1	28-Aug-11	0
Granite	1	28-Aug-11	3.47
Granite	2	28-Aug-11	1.77
Granite	2	28-Aug-11	0
Granite	2	28-Aug-11	2.69
Granite	2	28-Aug-11	5.44
Granite	2	28-Aug-11	0
Granite	3	28-Aug-11	0.65
Granite	3	28-Aug-11	0.39
Granite	3	28-Aug-11	0
Granite	3	28-Aug-11	1.7
Granite	3	28-Aug-11	1.31
Granite	1	18-Sep-11	1.77
Granite	1	18-Sep-11	0
Granite	1	18-Sep-11	1.9
Granite	1	18-Sep-11	0.46
Granite	1	18-Sep-11	2.75
Granite	2	18-Sep-11	1.83
Granite	2	18-Sep-11	0
Granite	2	18-Sep-11	1.11
Granite	2	18-Sep-11	0
Granite	2	18-Sep-11	1.11
Granite	3	18-Sep-11	1.64
Granite	3	18-Sep-11	7.07
Granite	3	18-Sep-11	0.07
Granite	3	18-Sep-11	1.24
Granite	3	18-Sep-11	1.77
Impacted	1	15-Mar-10	0.79
Impacted	1	15-Mar-10	0.72
Impacted	1	15-Mar-10	0.78
Impacted	1	15-Mar-10	0.73
Impacted	1	15-Mar-10	0.77
Impacted	2	15-Mar-10	0.53
Impacted	2	15-Mar-10	0.56
Impacted	2	15-Mar-10	0.58
Impacted	2	15-Mar-10	0.59
Impacted	2	15-Mar-10	0.59
Impacted	3	15-Mar-10	0.47
Impacted	3	15-Mar-10	0.49
Impacted	3	15-Mar-10	0.46
Impacted	3	15-Mar-10	0.51
Impacted	3	15-Mar-10	0.52
Impacted	1	29-Mar-10	0.58
Impacted	1	29-Mar-10	0.6
Impacted	1	29-Mar-10	0.56
Impacted	1	29-Mar-10	0.59
Impacted	1	29-Mar-10	0.54
Impacted	2	29-Mar-10	0.28
Impacted	2	29-Mar-10	0.33
Impacted	2	29-Mar-10	0.3
Impacted	2	29-Mar-10	0.24
Impacted	2	29-Mar-10	0.28
Impacted	3	29-Mar-10	0.27
Impacted	3	29-Mar-10	0.32
Impacted	3	29-Mar-10	0.3
Impacted	3	29-Mar-10	0.32
Impacted	3	29-Mar-10	0.4
Impacted	3	29-Mar-10	0.27
Impacted	1	2-Jul-10	1.05
Impacted	1	2-Jul-10	0.72
Impacted	1	2-Jul-10	0.92
Impacted	1	2-Jul-10	0
Impacted	1	2-Jul-10	0.79
Impacted	2	2-Jul-10	0.33
Impacted	2	2-Jul-10	1.51
Impacted	2	2-Jul-10	2.42
Impacted	2	2-Jul-10	1.44
Impacted	2	2-Jul-10	1.7
Impacted	2	2-Jul-10	1.64
Impacted	3	2-Jul-10	2.03
Impacted	3	2-Jul-10	1.44
Impacted	3	2-Jul-10	2.42
Impacted	3	2-Jul-10	0.13
Impacted	3	2-Jul-10	0
Impacted	3	2-Jul-10	1.64
Impacted	1	31-Jul-10	3.41
Impacted	1	31-Jul-10	6.35
Impacted	1	31-Jul-10	4.85
Impacted	1	31-Jul-10	4.91
Impacted	1	31-Jul-10	2.36
Impacted	2	31-Jul-10	2.62
Impacted	2	31-Jul-10	2.69
Impacted	2	31-Jul-10	3.08
Impacted	2	31-Jul-10	2.62
Impacted	2	31-Jul-10	2.62
Impacted	3	31-Jul-10	2.16
Impacted	3	31-Jul-10	1.77
Impacted	3	31-Jul-10	3.73
Impacted	3	31-Jul-10	1.77
Impacted	3	31-Jul-10	2.03
Impacted	1	26-Sep-10	0
Impacted	1	26-Sep-10	0

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Impacted	1	26-Sep-10	2.95
Impacted	1	26-Sep-10	1.9
Impacted	1	26-Sep-10	0.26
Impacted	1	26-Sep-10	2.69
Impacted	1	26-Sep-10	2.62
Impacted	2	26-Sep-10	2.16
Impacted	2	26-Sep-10	1.31
Impacted	2	26-Sep-10	1.96
Impacted	2	26-Sep-10	0
Impacted	2	26-Sep-10	0.65
Impacted	2	26-Sep-10	1.24
Impacted	2	26-Sep-10	0.52
Impacted	3	26-Sep-10	2.36
Impacted	3	26-Sep-10	1.31
Impacted	3	26-Sep-10	2.82
Impacted	3	26-Sep-10	3.54
Impacted	3	26-Sep-10	1.96
Impacted	3	26-Sep-10	3.14
Impacted	1	12-Feb-11	1.83
Impacted	1	12-Feb-11	1.89
Impacted	1	12-Feb-11	1.9
Impacted	1	12-Feb-11	2
Impacted	2	12-Feb-11	1.71
Impacted	2	12-Feb-11	2.04
Impacted	2	12-Feb-11	2.08
Impacted	2	12-Feb-11	1.48
Impacted	3	12-Feb-11	2.93
Impacted	3	12-Feb-11	2.18
Impacted	3	12-Feb-11	2.89
Impacted	3	12-Feb-11	2.8
Impacted	1	12-Mar-11	0.07
Impacted	1	12-Mar-11	0.07
Impacted	1	12-Mar-11	0.07
Impacted	1	12-Mar-11	0.08
Impacted	2	12-Mar-11	0.07
Impacted	2	12-Mar-11	0.09
Impacted	2	12-Mar-11	0.08
Impacted	2	12-Mar-11	0.06
Impacted	3	12-Mar-11	0.12
Impacted	3	12-Mar-11	0.09
Impacted	3	12-Mar-11	0.12
Impacted	3	12-Mar-11	0.11
Impacted	1	14-Apr-11	0.13
Impacted	1	14-Apr-11	0
Impacted	1	14-Apr-11	0.52
Impacted	1	14-Apr-11	0.46
Impacted	1	14-Apr-11	0.33
Impacted	2	14-Apr-11	0.65

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Impacted	2	14-Apr-11	0
Impacted	2	14-Apr-11	0.33
Impacted	2	14-Apr-11	0
Impacted	2	14-Apr-11	0
Impacted	3	14-Apr-11	0.33
Impacted	3	14-Apr-11	0
Impacted	3	14-Apr-11	0.2
Impacted	3	14-Apr-11	0.26
Impacted	3	14-Apr-11	0.13
Impacted	1	27-May-11	0.07
Impacted	1	27-May-11	0
Impacted	1	27-May-11	0
Impacted	1	27-May-11	0
Impacted	1	27-May-11	0.07
Impacted	2	27-May-11	0
Impacted	2	27-May-11	0.2
Impacted	2	27-May-11	0
Impacted	2	27-May-11	0
Impacted	2	27-May-11	0
Impacted	3	27-May-11	0
Impacted	3	27-May-11	0
Impacted	3	27-May-11	0.2
Impacted	3	27-May-11	0
Impacted	3	27-May-11	0
Impacted	1	28-May-11	0
Impacted	1	28-May-11	0.26
Impacted	1	28-May-11	0.13
Impacted	1	28-May-11	0.26
Impacted	1	28-May-11	0
Impacted	2	28-May-11	0.2
Impacted	2	28-May-11	0.13
Impacted	2	28-May-11	0
Impacted	2	28-May-11	0.13
Impacted	2	28-May-11	0
Impacted	3	28-May-11	0
Impacted	3	28-May-11	0.26
Impacted	3	28-May-11	0
Impacted	3	28-May-11	0
Impacted	3	28-May-11	0.2
Impacted	1	22-Jul-11	0
Impacted	1	22-Jul-11	0.65
Impacted	1	22-Jul-11	0
Impacted	1	22-Jul-11	0.59
Impacted	1	22-Jul-11	0
Impacted	2	22-Jul-11	0.2
Impacted	2	22-Jul-11	0.92
Impacted	2	22-Jul-11	0.79
Impacted	2	22-Jul-11	0.26

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Impacted	2	22-Jul-11	0.33
Impacted	3	22-Jul-11	0.65
Impacted	3	22-Jul-11	0.65
Impacted	3	22-Jul-11	0.65
Impacted	3	22-Jul-11	0.33
Impacted	3	22-Jul-11	0
Impacted	1	10-Aug-11	0
Impacted	1	10-Aug-11	0
Impacted	1	10-Aug-11	0
Impacted	1	10-Aug-11	0
Impacted	1	10-Aug-11	0
Impacted	1	10-Aug-11	0.46
Impacted	1	10-Aug-11	0.2
Impacted	1	10-Aug-11	3.41
Impacted	1	10-Aug-11	0.85
Impacted	1	10-Aug-11	1.57
Impacted	2	10-Aug-11	0
Impacted	2	10-Aug-11	0.72
Impacted	2	10-Aug-11	0
Impacted	2	10-Aug-11	1.05
Impacted	2	10-Aug-11	0
Impacted	3	10-Aug-11	0.98
Impacted	3	10-Aug-11	0.72
Impacted	3	10-Aug-11	0.52
Impacted	3	10-Aug-11	2.16
Impacted	3	10-Aug-11	0.52
Impacted	1	23-Sep-11	2.03
Impacted	1	23-Sep-11	3.01
Impacted	1	23-Sep-11	1.11
Impacted	1	23-Sep-11	1.05
Impacted	1	23-Sep-11	0
Impacted	2	23-Sep-11	2.69
Impacted	2	23-Sep-11	2.03
Impacted	2	23-Sep-11	1.64
Impacted	2	23-Sep-11	0.79
Impacted	2	23-Sep-11	0.52
Impacted	3	23-Sep-11	0.46
Impacted	3	23-Sep-11	0
Impacted	3	23-Sep-11	0.13
Impacted	3	23-Sep-11	0.26
Impacted	3	23-Sep-11	0.85
Meadow	1	2-Jul-10	2.23
Meadow	1	2-Jul-10	3.8
Meadow	1	2-Jul-10	3.47
Meadow	1	2-Jul-10	2.82
Meadow	1	2-Jul-10	4.06
Meadow	2	2-Jul-10	2.69
Meadow	2	2-Jul-10	6.81
Meadow	2	2-Jul-10	5.63
Meadow	2	2-Jul-10	4.58
Meadow	2	2-Jul-10	2.75
Meadow	3	2-Jul-10	4.32
Meadow	3	2-Jul-10	3.86
Meadow	3	2-Jul-10	4.19
Meadow	3	2-Jul-10	4.52
Meadow	3	2-Jul-10	5.7
Meadow	1	31-Jul-10	0.7
Meadow	1	31-Jul-10	0.72
Meadow	1	31-Jul-10	0.72
Meadow	1	31-Jul-10	0.84
Meadow	1	31-Jul-10	0.8
Meadow	2	31-Jul-10	0.52
Meadow	2	31-Jul-10	0.84
Meadow	2	31-Jul-10	1.18
Meadow	2	31-Jul-10	0.47
Meadow	2	31-Jul-10	1.03
Meadow	3	31-Jul-10	1.37
Meadow	3	31-Jul-10	0.86
Meadow	3	31-Jul-10	0.98
Meadow	3	31-Jul-10	0.87
Meadow	3	31-Jul-10	1.25
Meadow	1	26-Sep-10	0.39
Meadow	1	26-Sep-10	0.04
Meadow	1	26-Sep-10	0.36
Meadow	1	26-Sep-10	0.42
Meadow	1	26-Sep-10	0.57
Meadow	2	26-Sep-10	0.24
Meadow	2	26-Sep-10	0.16
Meadow	2	26-Sep-10	0.22
Meadow	2	26-Sep-10	0.01
Meadow	2	26-Sep-10	0.29
Meadow	3	26-Sep-10	0
Meadow	3	26-Sep-10	0.42
Meadow	3	26-Sep-10	0.66
Meadow	3	26-Sep-10	0.3
Meadow	3	26-Sep-10	0.48
Meadow	3	26-Sep-10	0.63
Meadow (east)	1	12-Feb-11	2.21
Meadow (east)	1	12-Feb-11	2.4
Meadow (east)	1	12-Feb-11	2.11
Meadow (east)	1	12-Feb-11	2.15
Meadow (east)	2	12-Feb-11	2.57
Meadow (east)	2	12-Feb-11	0.1
Meadow (east)	2	12-Feb-11	2.82
Meadow (east)	2	12-Feb-11	2.78
Meadow (east)	3	12-Feb-11	2.77

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Meadow (east)	1	12-Mar-11	0.09
Meadow (east)	1	12-Mar-11	0.1
Meadow (east)	1	12-Mar-11	0.08
Meadow (east)	1	12-Mar-11	0.09
Meadow (east)	2	12-Mar-11	0.1
Meadow (east)	2	12-Mar-11	0.11
Meadow (east)	2	12-Mar-11	0.11
Meadow (east)	2	12-Mar-11	0.11
Meadow (east)	3	12-Mar-11	0.09
Meadow (east)	3	12-Mar-11	0.09
Meadow (east)	3	12-Mar-11	0.11
Meadow (east)	3	12-Mar-11	0.11
Meadow (east)	1	27-May-11	0
Meadow (east)	1	27-May-11	0.59
Meadow (east)	1	27-May-11	1.57
Meadow (east)	1	27-May-11	0.2
Meadow (east)	1	27-May-11	4.13
Meadow (east)	2	27-May-11	2.62
Meadow (east)	2	27-May-11	0.85
Meadow (east)	2	27-May-11	4.58
Meadow (east)	2	27-May-11	0.85
Meadow (east)	2	27-May-11	1.31
Meadow (east)	3	27-May-11	0.46
Meadow (east)	3	27-May-11	0.39
Meadow (east)	3	27-May-11	1.57
Meadow (east)	3	27-May-11	0.2
Meadow (east)	3	27-May-11	8.97
Meadow (east)	3	27-May-11	10.02
Meadow (east)	1	22-Jul-11	2.88
Meadow (east)	1	22-Jul-11	5.83
Meadow (east)	1	22-Jul-11	4.13
Meadow (east)	1	22-Jul-11	4.98
Meadow (east)	1	22-Jul-11	3.54
Meadow (east)	2	22-Jul-11	4.85
Meadow (east)	2	22-Jul-11	5.57
Meadow (east)	2	22-Jul-11	7.66
Meadow (east)	2	22-Jul-11	4.32
Meadow (east)	2	22-Jul-11	4.45
Meadow (east)	3	22-Jul-11	6.22
Meadow (east)	3	22-Jul-11	4.32
Meadow (east)	3	22-Jul-11	8.19
Meadow (east)	3	22-Jul-11	11.27
Meadow (east)	3	22-Jul-11	9.1
Meadow (east)	1	10-Aug-11	3.73
Meadow (east)	1	10-Aug-11	2.69
Meadow (east)	1	10-Aug-11	4.65
Meadow (east)	1	10-Aug-11	9.96
Meadow (east)	1	10-Aug-11	10.09

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Meadow (east)	2	10-Aug-11	6.35
Meadow (east)	2	10-Aug-11	3.41
Meadow (east)	2	10-Aug-11	1.11
Meadow (east)	2	10-Aug-11	4.39
Meadow (east)	2	10-Aug-11	7.79
Meadow (east)	3	10-Aug-11	4.65
Meadow (east)	3	10-Aug-11	4.65
Meadow (east)	3	10-Aug-11	4.26
Meadow (east)	3	10-Aug-11	5.83
Meadow (east)	3	10-Aug-11	3.41
Meadow (east)	1	23-Sep-11	7.2
Meadow (east)	1	23-Sep-11	5.31
Meadow (east)	1	23-Sep-11	5.96
Meadow (east)	1	23-Sep-11	4.32
Meadow (east)	1	23-Sep-11	4.72
Meadow (east)	2	23-Sep-11	5.83
Meadow (east)	2	23-Sep-11	3.27
Meadow (east)	2	23-Sep-11	3.34
Meadow (east)	2	23-Sep-11	6.35
Meadow (east)	2	23-Sep-11	3.21
Meadow (east)	3	23-Sep-11	3.47
Meadow (east)	3	23-Sep-11	3.86
Meadow (east)	3	23-Sep-11	4.39
Meadow (east)	3	23-Sep-11	6.16
Meadow (east)	3	23-Sep-11	5.5
Meadow (west)	1	12-Feb-11	2.4
Meadow (west)	1	12-Feb-11	3.22
Meadow (west)	1	12-Feb-11	2.87
Meadow (west)	1	12-Feb-11	2.73
Meadow (west)	1	12-Feb-11	2.86
Meadow (west)	2	12-Feb-11	3.02
Meadow (west)	2	12-Feb-11	3.06
Meadow (west)	2	12-Feb-11	2.5
Meadow (west)	2	12-Feb-11	2.56
Meadow (west)	3	12-Feb-11	1.83
Meadow (west)	3	12-Feb-11	1.91
Meadow (west)	3	12-Feb-11	1.9
Meadow (west)	3	12-Feb-11	2.13
Meadow (west)	1	12-Mar-11	0.09
Meadow (west)	1	12-Mar-11	0.13
Meadow (west)	1	12-Mar-11	0.11
Meadow (west)	1	12-Mar-11	0.11
Meadow (west)	1	12-Mar-11	0.11
Meadow (west)	2	12-Mar-11	0.09
Meadow (west)	2	12-Mar-11	0.12
Meadow (west)	2	12-Mar-11	0.12
Meadow (west)	2	12-Mar-11	0.1
Meadow (west)	2	12-Mar-11	0.1

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Meadow (west)	3	12-Mar-11	0.07
Meadow (west)	3	12-Mar-11	0.08
Meadow (west)	3	12-Mar-11	0.08
Meadow (west)	3	12-Mar-11	0.09
Meadow (west)	1	14-Apr-11	0.98
Meadow (west)	1	14-Apr-11	0.85
Meadow (west)	1	14-Apr-11	0.65
Meadow (west)	1	14-Apr-11	0
Meadow (west)	2	14-Apr-11	1.77
Meadow (west)	2	14-Apr-11	0.2
Meadow (west)	2	14-Apr-11	1.24
Meadow (west)	2	14-Apr-11	0.98
Meadow (west)	1	27-May-11	0.52
Meadow (west)	1	27-May-11	0.65
Meadow (west)	1	27-May-11	0.07
Meadow (west)	1	27-May-11	0.26
Meadow (west)	1	27-May-11	0.65
Meadow (west)	2	27-May-11	1.24
Meadow (west)	2	27-May-11	1.11
Meadow (west)	2	27-May-11	1.77
Meadow (west)	2	27-May-11	1.9
Meadow (west)	2	27-May-11	1.7
Meadow (west)	3	27-May-11	0.85
Meadow (west)	3	27-May-11	4.91
Meadow (west)	3	27-May-11	4.39
Meadow (west)	3	27-May-11	1.18
Meadow (west)	3	27-May-11	1.31
Meadow (west)	1	21-Jul-11	4.65
Meadow (west)	1	21-Jul-11	4.13
Meadow (west)	1	21-Jul-11	1.83
Meadow (west)	1	21-Jul-11	1.18
Meadow (west)	1	21-Jul-11	2.75
Meadow (west)	2	21-Jul-11	2.55
Meadow (west)	2	21-Jul-11	4.32
Meadow (west)	2	21-Jul-11	2.69
Meadow (west)	2	21-Jul-11	1.64
Meadow (west)	2	21-Jul-11	0.46
Meadow (west)	2	22-Jul-11	3.34
Meadow (west)	2	22-Jul-11	3.01
Meadow (west)	2	22-Jul-11	3.34
Meadow (west)	2	22-Jul-11	1.31
Meadow (west)	2	22-Jul-11	0.85
Meadow (west)	3	22-Jul-11	1.38
Meadow (west)	3	22-Jul-11	4
Meadow (west)	3	22-Jul-11	2.23
Meadow (west)	3	22-Jul-11	3.01
Meadow (west)	3	22-Jul-11	4.98
Meadow (west)	1	10-Aug-11	1.96
Meadow (west)	1	10-Aug-11	3.86
Meadow (west)	1	10-Aug-11	5.63
Meadow (west)	1	10-Aug-11	5.31
Meadow (west)	1	10-Aug-11	4.52
Meadow (west)	2	10-Aug-11	4.52
Meadow (west)	2	10-Aug-11	2.88
Meadow (west)	2	10-Aug-11	4.32
Meadow (west)	2	10-Aug-11	5.24
Meadow (west)	2	10-Aug-11	3.34
Meadow (west)	3	10-Aug-11	5.57
Meadow (west)	3	10-Aug-11	3.6
Meadow (west)	3	10-Aug-11	0.2
Meadow (west)	3	10-Aug-11	5.7
Meadow (west)	3	10-Aug-11	6.09
Meadow (west)	1	23-Sep-11	3.14
Meadow (west)	1	23-Sep-11	1.96
Meadow (west)	1	23-Sep-11	2.55
Meadow (west)	1	23-Sep-11	4.19
Meadow (west)	1	23-Sep-11	5.24
Meadow (west)	2	23-Sep-11	2.49
Meadow (west)	2	23-Sep-11	4.65
Meadow (west)	2	23-Sep-11	4.85
Meadow (west)	2	23-Sep-11	4.32
Meadow (west)	2	23-Sep-11	3.93
Meadow (west)	3	23-Sep-11	1.51
Meadow (west)	3	23-Sep-11	3.27
Meadow (west)	3	23-Sep-11	4.58
Meadow (west)	3	23-Sep-11	0
Meadow (west)	3	23-Sep-11	2.82
Schist	1	6-Mar-10	0.52
Schist	1	6-Mar-10	0.56
Schist	1	6-Mar-10	0.28
Schist	1	6-Mar-10	0.58
Schist	1	6-Mar-10	0.47
Schist	1	6-Mar-10	0.68
Schist	1	6-Mar-10	0.63
Schist	1	6-Mar-10	0.66
Schist	1	6-Mar-10	0.65
Schist	2	6-Mar-10	0.61
Schist	2	6-Mar-10	0.56
Schist	2	6-Mar-10	0.59
Schist	2	6-Mar-10	0.33
Schist	2	6-Mar-10	0.43
Schist	2	6-Mar-10	0.4
Schist	2	6-Mar-10	0.41
Schist	2	6-Mar-10	0.38
Schist	2	6-Mar-10	0.41
Schist	3	6-Mar-10	0.61

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Schist	3	6-Mar-10	0.56
Schist	3	6-Mar-10	0.59
Schist	3	6-Mar-10	0.53
Schist	3	6-Mar-10	0.27
Schist	3	6-Mar-10	0.12
Schist	3	6-Mar-10	0.14
Schist	3	6-Mar-10	0.07
Schist	3	6-Mar-10	0.07
Schist	4	6-Mar-10	0.39
Schist	4	6-Mar-10	0.35
Schist	4	6-Mar-10	0.37
Schist	4	6-Mar-10	0.4
Schist	4	6-Mar-10	0.32
Schist	1	22-Mar-10	0.77
Schist	1	22-Mar-10	0.88
Schist	1	22-Mar-10	0.6
Schist	1	22-Mar-10	0.31
Schist	1	22-Mar-10	0.42
Schist	2	22-Mar-10	0.37
Schist	2	22-Mar-10	0.48
Schist	2	22-Mar-10	0.51
Schist	2	22-Mar-10	0.45
Schist	2	22-Mar-10	0.56
Schist	3	22-Mar-10	0.61
Schist	3	22-Mar-10	0.91
Schist	3	22-Mar-10	0.9
Schist	3	22-Mar-10	0.89
Schist	3	22-Mar-10	0.67
Schist	4	22-Mar-10	0.61
Schist	4	22-Mar-10	0.61
Schist	4	22-Mar-10	0.53
Schist	4	22-Mar-10	0.43
Schist	4	22-Mar-10	0.41
Schist	4	29-Jun-10	4.58
Schist	4	29-Jun-10	8.71
Schist	4	29-Jun-10	4.45
Schist	5	29-Jun-10	1.38
Schist	5	29-Jun-10	6.55
Schist	5	29-Jun-10	8.58
Schist	5	29-Jun-10	4.13
Schist	5	29-Jun-10	4
Schist	5	29-Jun-10	8.38
Schist	1	15-Jul-10	0.85
Schist	1	15-Jul-10	0.52
Schist	1	15-Jul-10	0.79
Schist	1	15-Jul-10	0.39
Schist	1	15-Jul-10	0.72
Schist	2	15-Jul-10	4.58
Schist	2	15-Jul-10	4.85
Schist	2	15-Jul-10	9.76
Schist	2	15-Jul-10	1.57
Schist	2	15-Jul-10	1.83
Schist	3	15-Jul-10	1.77
Schist	3	15-Jul-10	0.85
Schist	3	15-Jul-10	1.64
Schist	3	15-Jul-10	0.72
Schist	3	15-Jul-10	1.05
Schist	4	15-Jul-10	8.91
Schist	4	15-Jul-10	8.45
Schist	4	15-Jul-10	4.98
Schist	4	15-Jul-10	4.91
Schist	4	15-Jul-10	4.26
Schist	5	15-Jul-10	5.17
Schist	5	15-Jul-10	4.91
Schist	5	15-Jul-10	5.44
Schist	5	15-Jul-10	5.57
Schist	5	15-Jul-10	4.85
Schist	1	28-Jul-10	1.11
Schist	1	28-Jul-10	0.33
Schist	1	28-Jul-10	0
Schist	1	28-Jul-10	1.11
Schist	1	28-Jul-10	0.2
Schist	2	28-Jul-10	0
Schist	2	28-Jul-10	0.65
Schist	2	28-Jul-10	0.59
Schist	2	28-Jul-10	2.75
Schist	2	28-Jul-10	1.64
Schist	3	28-Jul-10	1.24
Schist	3	28-Jul-10	0.2
Schist	3	28-Jul-10	0.07
Schist	3	28-Jul-10	0.39
Schist	3	28-Jul-10	1.64
Schist	1	12-Sep-10	4.85
Schist	1	12-Sep-10	4.98
Schist	1	12-Sep-10	3.93
Schist	1	12-Sep-10	5.96
Schist	1	12-Sep-10	5.63
Schist	2	12-Sep-10	5.7
Schist	2	12-Sep-10	4.85
Schist	2	12-Sep-10	7.2
Schist	2	12-Sep-10	4.85
Schist	2	12-Sep-10	5.57
Schist	3	12-Sep-10	1.9
Schist	3	12-Sep-10	1.77
Schist	3	12-Sep-10	2.49
Schist	3	12-Sep-10	4.65

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Schist	3	12-Sep-10	2.29
Schist	4	12-Sep-10	4.13
Schist	4	12-Sep-10	1.24
Schist	4	12-Sep-10	5.24
Schist	4	12-Sep-10	6.35
Schist	4	12-Sep-10	4.78
Schist	5	12-Sep-10	5.83
Schist	5	12-Sep-10	3.54
Schist	5	12-Sep-10	5.37
Schist	5	12-Sep-10	4.19
Schist	5	12-Sep-10	5.24
Schist	1	6-Feb-11	0
Schist	1	6-Feb-11	0
Schist	1	6-Feb-11	0
Schist	1	6-Feb-11	0
Schist	1	6-Feb-11	0
Schist	2	6-Feb-11	0
Schist	2	6-Feb-11	0
Schist	2	6-Feb-11	0
Schist	2	6-Feb-11	0
Schist	2	6-Feb-11	0
Schist	3	6-Feb-11	0
Schist	3	6-Feb-11	0
Schist	3	6-Feb-11	0
Schist	3	6-Feb-11	0
Schist	3	6-Feb-11	0
Schist	1	7-Mar-11	0.2
Schist	1	7-Mar-11	0.26
Schist	1	7-Mar-11	0.13
Schist	1	7-Mar-11	2.16
Schist	1	7-Mar-11	0.39
Schist	2	7-Mar-11	0.2
Schist	2	7-Mar-11	0
Schist	2	7-Mar-11	0.39
Schist	2	7-Mar-11	0.33
Schist	2	7-Mar-11	0
Schist	3	7-Mar-11	0.39
Schist	3	7-Mar-11	0.26
Schist	3	7-Mar-11	0
Schist	3	7-Mar-11	0
Schist	3	7-Mar-11	0
Schist	1	11-Apr-11	0.39
Schist	1	11-Apr-11	0.92
Schist	1	11-Apr-11	0.98
Schist	1	11-Apr-11	0.33
Schist	1	11-Apr-11	0.92
Schist	2	11-Apr-11	0.2
Schist	2	11-Apr-11	0.72
Schist	2	11-Apr-11	0.52
Schist	2	11-Apr-11	0.52
Schist	2	11-Apr-11	0.98
Schist	3	11-Apr-11	0.2
Schist	3	11-Apr-11	0.26
Schist	3	11-Apr-11	0.79
Schist	3	11-Apr-11	0.65
Schist	3	11-Apr-11	0.79
Schist	1	19-May-11	0.52
Schist	1	19-May-11	0
Schist	1	19-May-11	0
Schist	1	19-May-11	1.05
Schist	1	19-May-11	0
Schist	1	19-May-11	0.92
Schist	2	19-May-11	1.18
Schist	2	19-May-11	0.85
Schist	2	19-May-11	0.2
Schist	2	19-May-11	1.18
Schist	2	19-May-11	1.18
Schist	3	19-May-11	0.13
Schist	3	19-May-11	0.2
Schist	3	19-May-11	0
Schist	3	19-May-11	5.76
Schist	3	19-May-11	0
Schist	1	22-Jun-11	0.39
Schist	1	22-Jun-11	0.92
Schist	1	22-Jun-11	0.85
Schist	1	22-Jun-11	0.85
Schist	1	22-Jun-11	0.46
Schist	2	22-Jun-11	1.18
Schist	2	22-Jun-11	0
Schist	2	22-Jun-11	0.07
Schist	2	22-Jun-11	0.26
Schist	2	22-Jun-11	0.2
Schist	3	22-Jun-11	0.2
Schist	3	22-Jun-11	1.24
Schist	3	22-Jun-11	0.52
Schist	3	22-Jun-11	0.26
Schist	3	22-Jun-11	0.46
Schist	1	28-Aug-11	0.65
Schist	1	28-Aug-11	0.65
Schist	1	28-Aug-11	3.47
Schist	1	28-Aug-11	3.08
Schist	1	28-Aug-11	1.18
Schist	2	28-Aug-11	0.79
Schist	2	28-Aug-11	3.08
Schist	2	28-Aug-11	4.52
Schist	2	28-Aug-11	2.88

Site	Plot	Date Collected	Gas Flux (gC/m^2/d)
Schist	2	28-Aug-11	6.81
Schist	3	28-Aug-11	1.38
Schist	3	28-Aug-11	4.98
Schist	3	28-Aug-11	1.83
Schist	3	28-Aug-11	1.51
Schist	3	28-Aug-11	4.32
Schist	1	18-Sep-11	4.32
Schist	1	18-Sep-11	4.91
Schist	1	18-Sep-11	0.59
Schist	1	18-Sep-11	0.98
Schist	1	18-Sep-11	0.33
Schist	2	18-Sep-11	0
Schist	2	18-Sep-11	1.24
Schist	2	18-Sep-11	0.92
Schist	2	18-Sep-11	3.14
Schist	2	18-Sep-11	0
Schist	3	18-Sep-11	0.92
Schist	3	18-Sep-11	2.62
Schist	3	18-Sep-11	0.92
Schist	3	18-Sep-11	6.16

Table E.4 Stable isotopes of C and N and bulk soil C and N.

Site	**plot**	**$\delta^{13}C$**	**$\delta^{15}N$**	**Bulk C (mg C/g dry soil)**	**Bulk N (mg N/g dry soil)**
Schist	1	-24.82	0.85	64.70	2.99
Schist	1	-25.27	0.80	77.55	3.41
Schist	1	-24.69	1.88	74.07	3.32
Schist	2	-25.21	2.11	87.54	5.13
Schist	2	-25.05	1.52	83.93	4.74
Schist	2	-24.75	2.81	74.06	4.67
Schist	3	-25.10	-0.07	79.81	3.58
Schist	3	-25.47	0.43	102.96	4.34
Schist	3	-25.38	0.16	85.53	3.90
Granite	1	-25.12	-0.50	59.59	2.94
Granite	1	-25.26	-0.46	74.61	3.18
Granite	1	-24.97	0.31	60.68	2.76
Granite	2	-25.45	-0.66	62.46	2.99
Granite	2	-25.62	1.00	63.32	2.54
Granite	2	-25.54	0.47	68.37	3.05
Granite	3	-25.39	0.76	62.56	3.01
Granite	3	-25.31	0.14	74.72	2.76
Granite	3	-25.50	0.25	84.25	3.18
Flux Tower	1	-25.76	1.87	158.42	8.42
Flux Tower	1	-25.37	2.15	231.42	9.99
Flux Tower	1	-25.62	1.51	273.41	10.96
Flux Tower	2	-25.39	1.44	309.55	13.28
Flux Tower	2	-25.19	1.67	317.05	15.08
Flux Tower	2	-25.20	0.89	340.74	17.46
Flux Tower	3	-26.03	-0.37	228.28	11.37
Flux Tower	3	-26.27	0.61	265.72	13.52
Flux Tower	3	-25.57	0.56	172.21	8.97
West Zob Forest	1	-25.66	1.03	106.33	5.62
West Zob Forest	1	-25.68	2.09	93.17	5.05
West Zob Forest	1	-25.60	2.17	73.97	4.26
West Zob Forest	2	-25.46	1.81	104.22	5.66
West Zob Forest	2	-25.41	1.39	74.08	3.93
West Zob Forest	2	-25.00	1.87	78.65	4.04
West Zob Forest	3	-25.03	0.73	162.14	5.78
West Zob Forest	3	-25.83	1.59	186.56	8.15
West Zob Forest	3	-25.69	1.00	150.99	6.60
West Zob Meadow	1	-26.02	1.20	118.06	6.02
West Zob Meadow	1	-26.17	1.72	136.72	6.76
West Zob Meadow	1	-26.09	1.52	159.40	8.08
West Zob Meadow	2	-25.90	1.33	113.44	5.04
West Zob Meadow	2	-25.74	0.02	96.98	4.52
West Zob Meadow	2	-25.48	2.04	71.46	3.60

Site	plot	$\delta^{13}C$	$\delta^{15}N$	Bulk C (mg C/g dry soil)	Bulk N (mg N/g dry soil)
West Zob Meadow	3	-25.50	0.68	218.31	9.06
West Zob Meadow	3	-25.78	0.78	148.51	6.73
West Zob Meadow	3	-25.46	0.48	121.93	5.45
East Zob Forest	1	-25.92	3.63	155.90	11.97
East Zob Forest	1	-25.51	3.75	58.24	4.34
East Zob Forest	1	-25.34	2.37	61.98	4.86
East Zob Forest	2	-25.73	3.02	87.40	6.20
East Zob Forest	2	-26.00	3.24	75.62	5.11
East Zob Forest	2	-26.59	2.39	118.70	7.57
East Zob Forest	3	-25.99	3.32	54.49	3.90
East Zob Forest	3	-25.67	3.01	49.83	3.99
East Zob Forest	3	-25.41	2.93	47.49	3.52
East Zob Meadow	1	-26.71	2.43	193.33	11.32
East Zob Meadow	1	-26.38	2.16	222.98	12.77
East Zob Meadow	1	-26.53	2.09	235.31	13.82
East Zob Meadow	2	-26.15	0.99	326.92	18.79
East Zob Meadow	2	-26.21	1.57	337.57	19.04
East Zob Meadow	2	-26.06	1.82	169.47	11.28
East Zob Meadow	3	-24.58	2.47	57.08	3.95
East Zob Meadow	3	-24.61	1.90	46.68	3.30
East Zob Meadow	3	-24.90	3.85	75.19	5.11

APPENDIX G: FIGURES

LIST OF FIGURES

APPENDIX G: FIGURES

LIST OF FIGURES – *Continued*

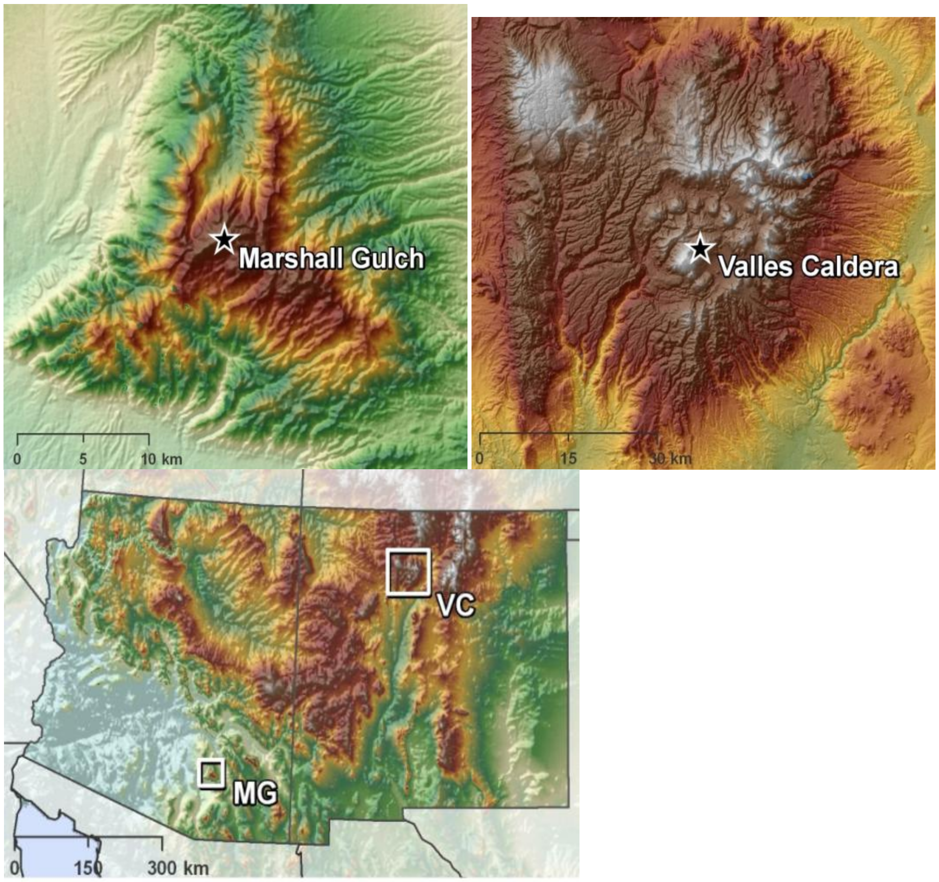

Figure 1. Map illustrating locations of study sites in Arizona and New Mexico.

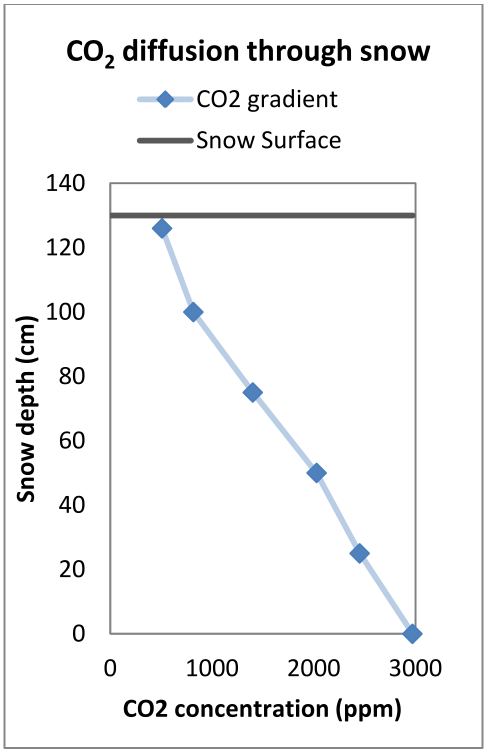

Figure 2. CO_2 concentration profile through 130cm deep snowpack.

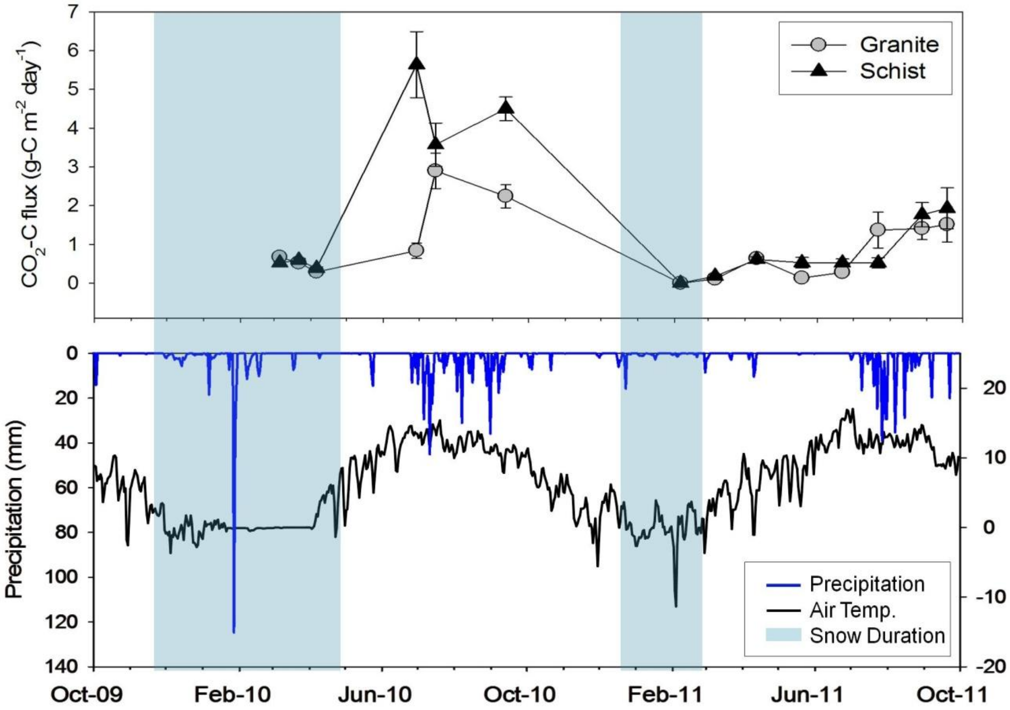

Figure 3. Time series of interpolated CO_2 fluxes for coarse (granitic) and fine (schist) soils (top), and daily precipitation, mean daily temperature, and snow cover duration (bottom) for water years 2010 and 2011. Error bars show standard error for site/date sample collection pairs.

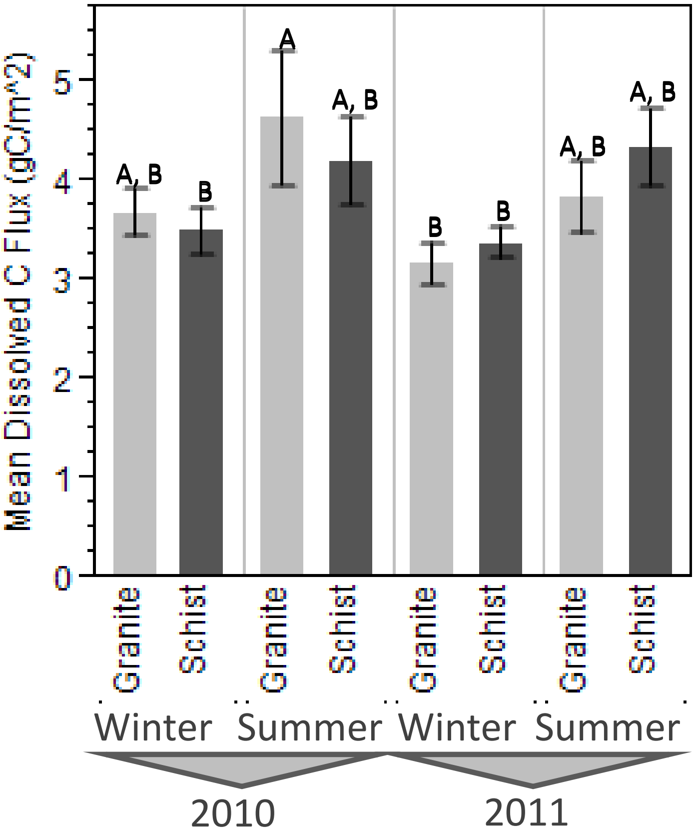

Figure 4. Mean seasonal DOC flux for granite and schist soils through snowmelt (winter) and monsoon (summer) of 2010 and 2011. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

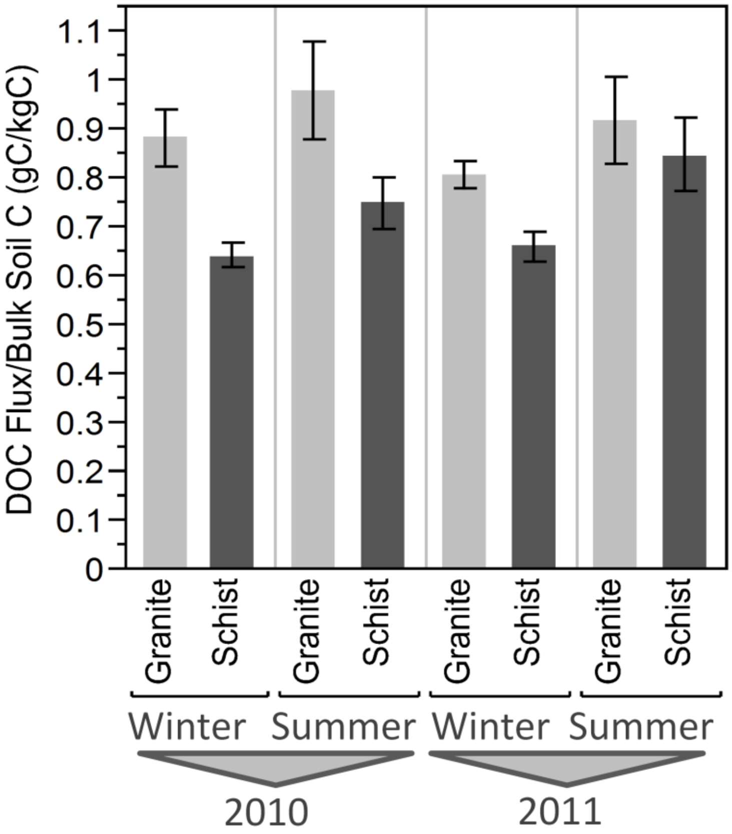

Figure 5. Mean seasonal DOC flux (g C m^{-2}) normalized by bulk soil C (kg C m^{-2}) for granite and schist soils through snowmelt (winter) and monsoon (summer) of 2010 and 2011. Error bars show one standard error. Granite soils have significantly higher normalized DOC fluxes than schist soils during Melt 2010, Monsoon 2010 and Melt 2011 ($p<0.05$).

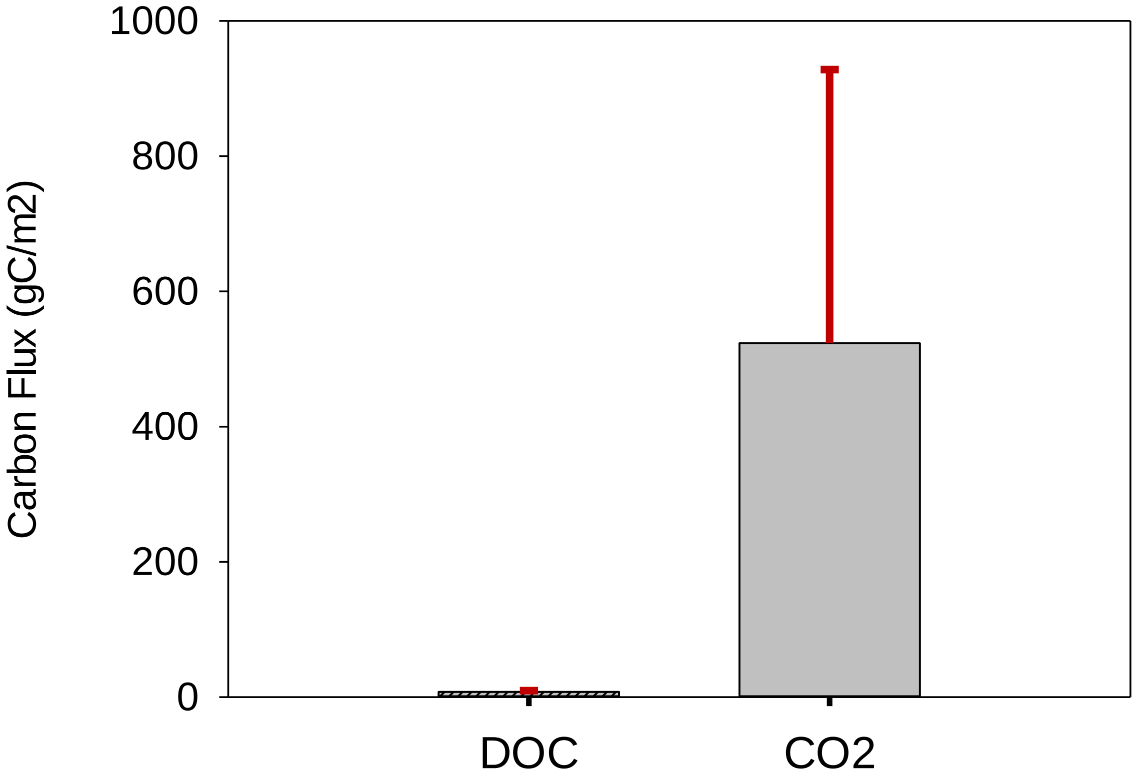

Figure 6. Mean annual DOC flux (7.7±1 .9 g C/year) and mean annual CO_2 flux (523 ± 405 g C.year). Error bars show standard error.

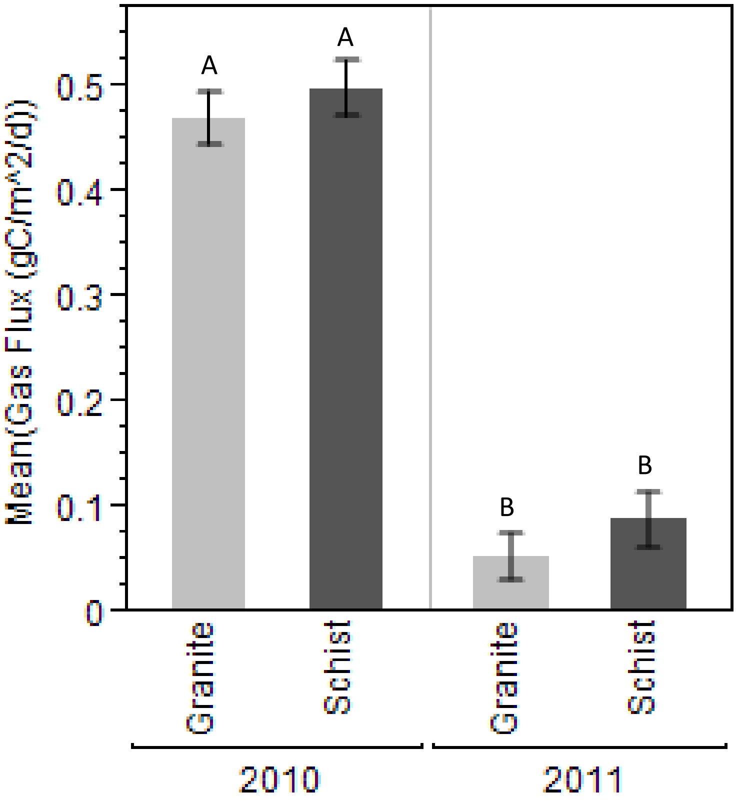

Figure 7. Mean daily CO_2 flux for granite and schist soils during winter of 2010 and 2011. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

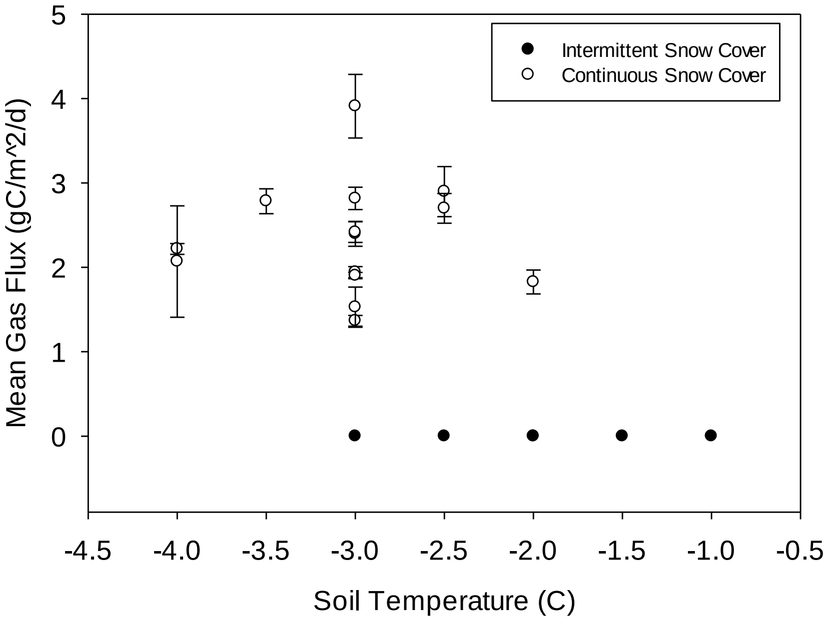

Figure 8. Relationship between soil temperature and mean gas flux for ephemerally snow covered and continuously snow covered sites. Ephemeral sites are at Marshall Gulch during 2011; continuous sites are from Marshall Gulch in 2011 and Valles Caldera 2010 and 2011. Error bars show one standard error from the mean for date/sites sampling pairs.

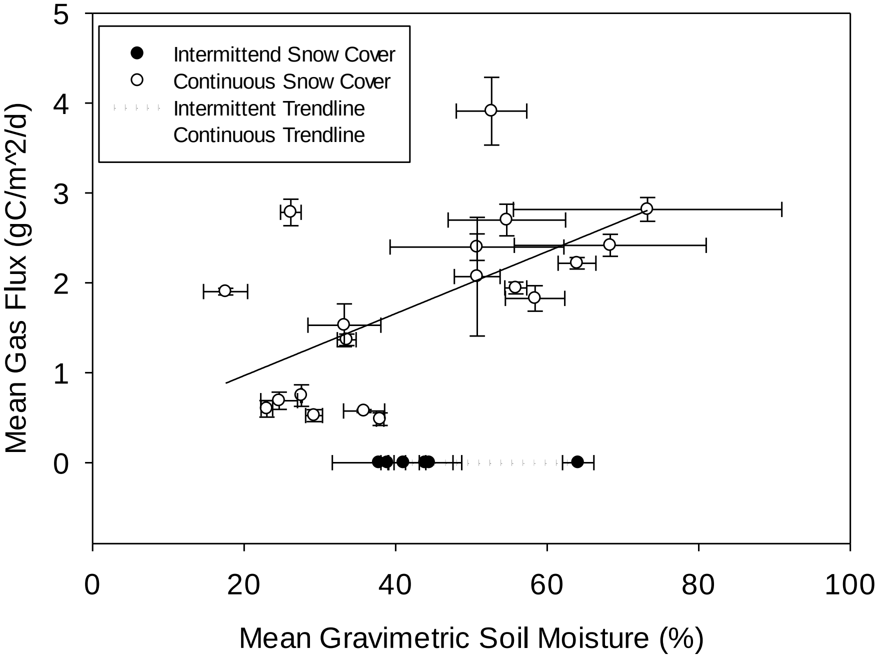

Figure 9. Relationship between soil temperature and mean gas flux for ephemerally snow covered and continuously snow covered sites. Error bars show one standard error. Ephemerally snow covered sites show have no flux despite variable moisture. Continuously snow covered sites show a significant positive relationship (*R^2=0.35, p<0.0071).*

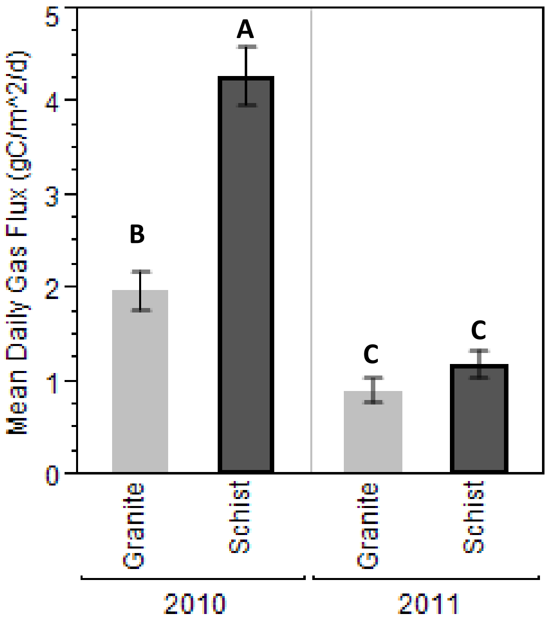

Figure 10. Mean daily CO_2 flux for granite and schist soils during the growing season of 2010 and 2011. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

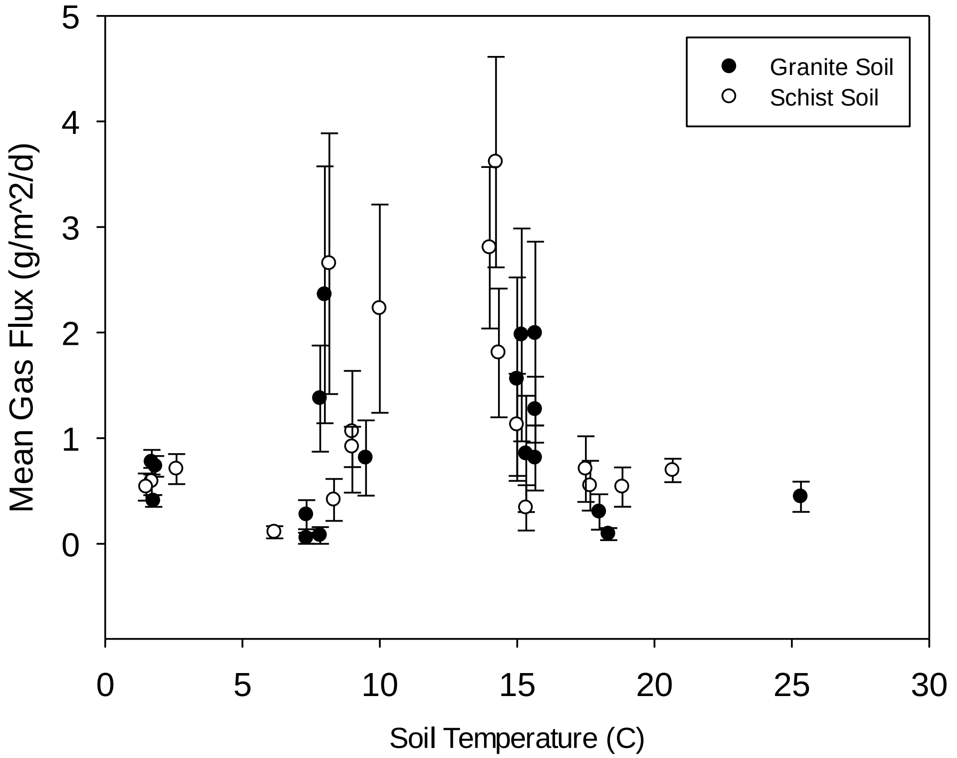

Figure 11. Relationship between soil temperature and mean gas flux for fine schist soils and coarse granitic soils during the growing season. Error bars show one standard error from the mean for date/site sampling pairs.

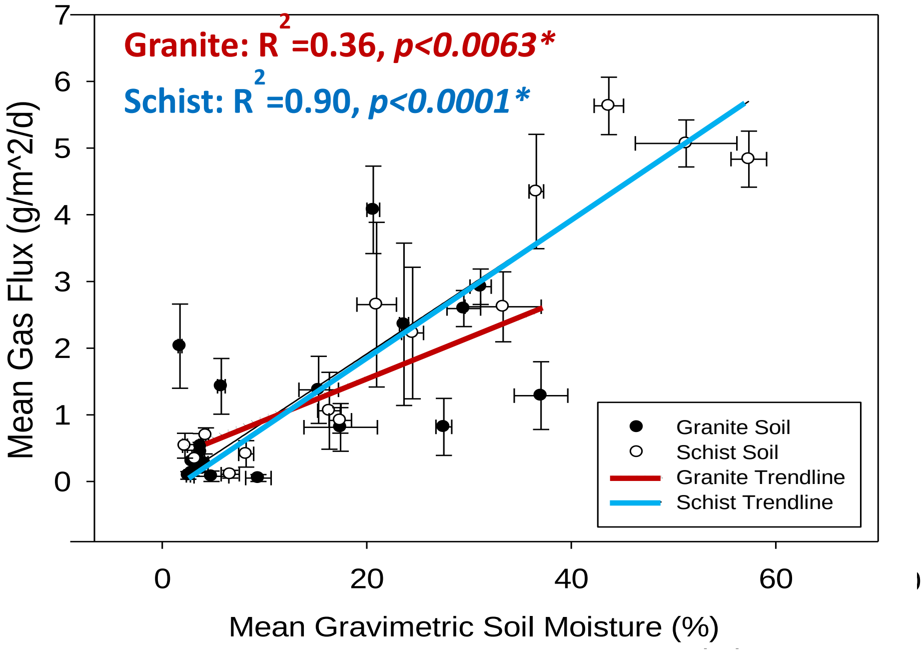

Figure 12. Relationship between soil temperature and mean gas flux for fine schist and coarse granitic soils during the growing season. Error bars show one standard error.

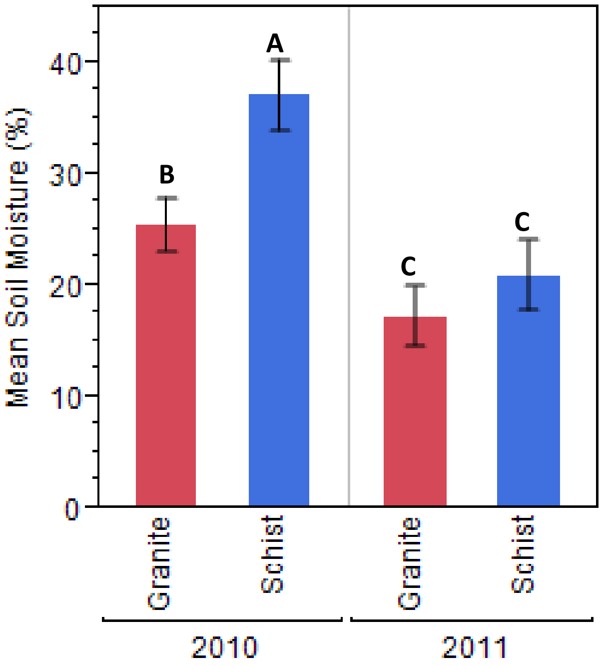

Figure 13. Mean gravimetric soil moisture for schist and granite soils during summer, 2010 and 2011. Error bars show one standard error. Values not connected by the same letter are significantly different (p<0.05).

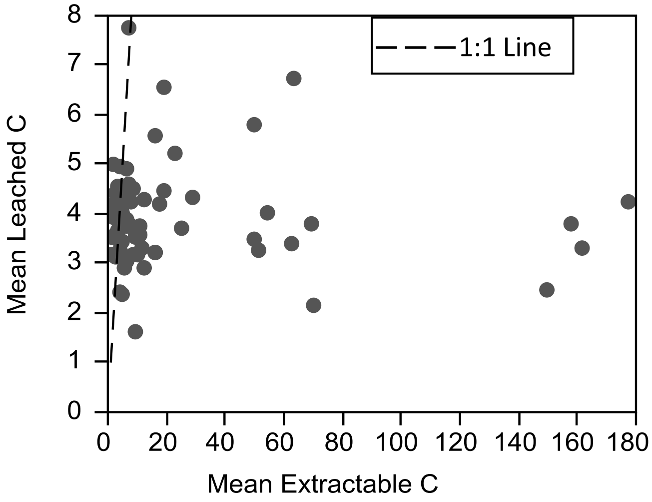

Figure B.1. Relationship between leached C and extractable C.

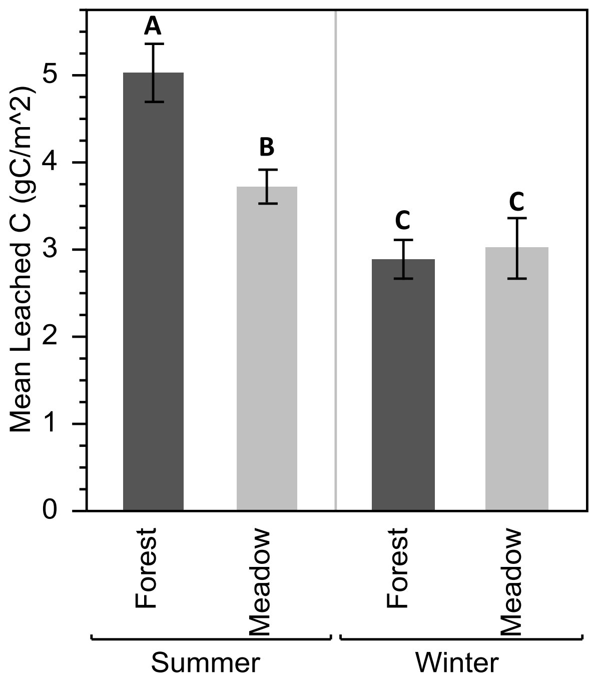

Figure C.1. Mean seasonal dissolved flux for forest and meadow during summer and winter, 2011. Error bars show one standard error. Values not connected by the same letter are significantly different (p<0.05).

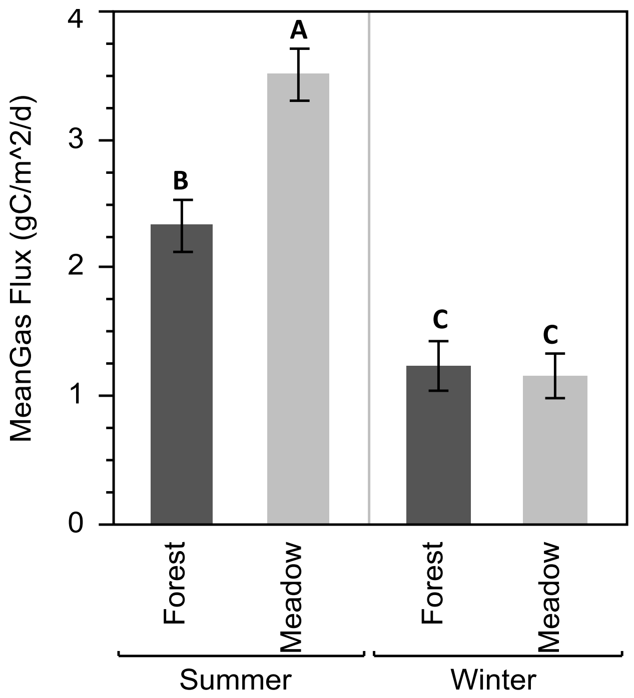

Figure C.2. Mean daily gas flux for forest and meadow during summer and winter. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

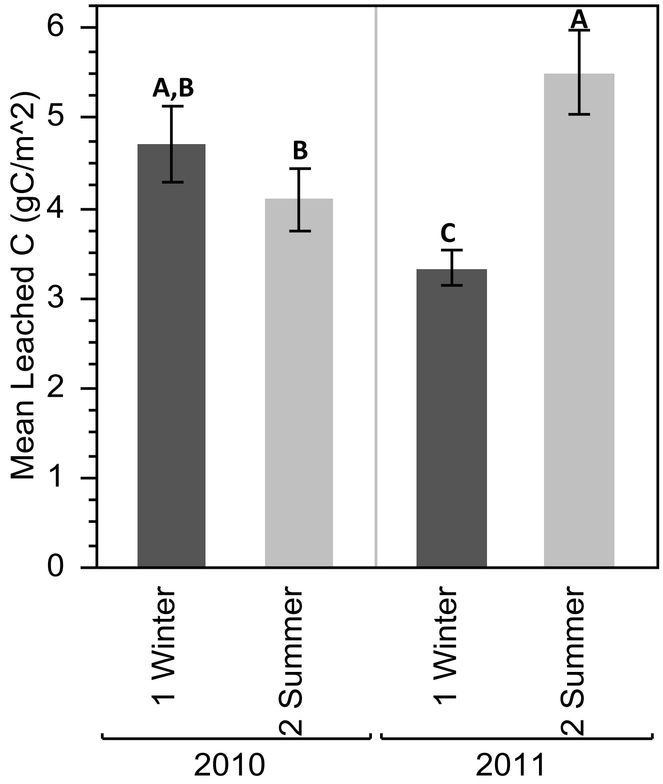

Figure C.3. Winter and summer mean seasonal dissolved flux for forested sites impacted by *C. occidentalis* during 2010 and 2011. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

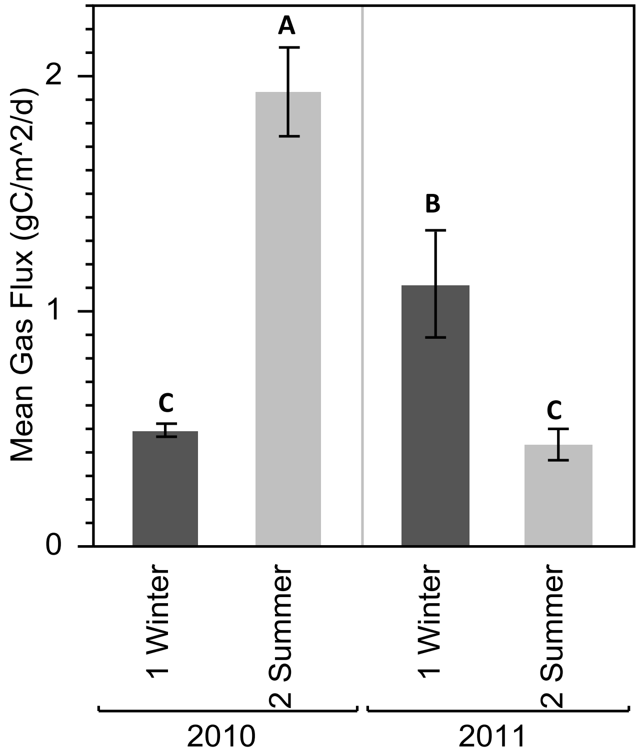

Figure C.4. Winter and summer mean daily gaseous flux for forested sites impacted by *C. occidentalis* during 2010 and 2011. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

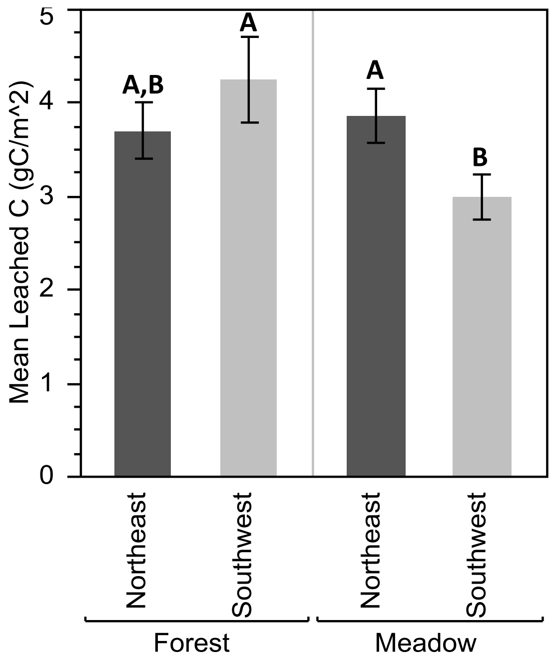

Figure D.1. Mean dissolved flux for forest and meadow sites with northeast and southwest aspects. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).

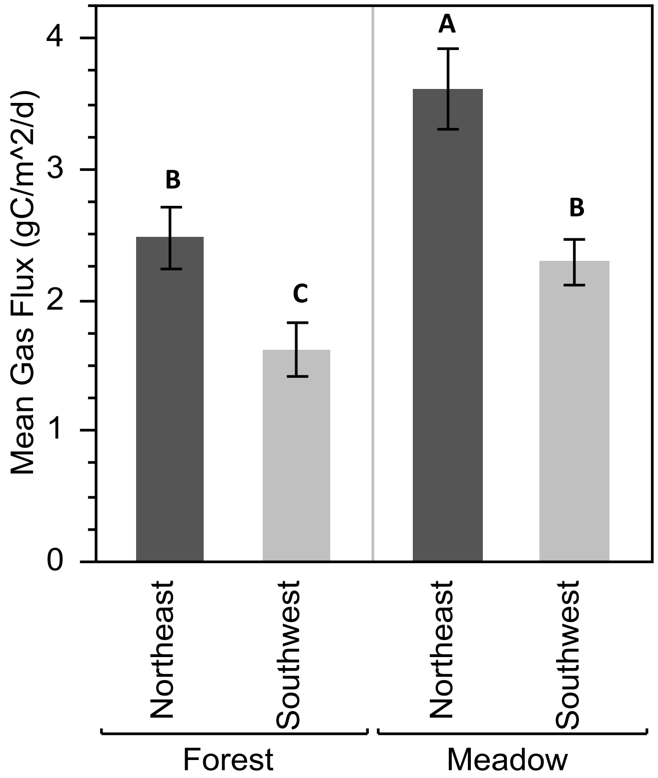

Figure D.2. Mean gas flux for forest and meadow sites with northeast and southwest aspects. Error bars show one standard error. Values not connected by the same letter are significantly different ($p<0.05$).