Report as of FY2006 for 2006IN190B: "Trace Gas Fluxes in Riparian Buffers along an Urban Rural Gradient"

Publications

- Conference Proceedings:
  - Jacinthe, P.A., L. Tedesco, R.C. Barr. 2006. Soil properties and trace gas fluxes in a newly-restored riparian forest. Annual meeting of the American Society of Agronomy, Indianapolis. Session 304, Abstract 831: http://a-c-s.confex.com/crops/2006am/techprogram/P24858.htm
  - Jacinthe, P.A., J.S. Bills, L. Tedesco, R.C. Barr. 2007. Hydro-climatic events and greenhouse gas dynamics in riparian forests. Fourth USDA Greenhouse Gas Conference, Baltimore. Session 11, Abstract 213. http://a-c-s.confex.com/a-c-s/usda/techprogram/P29334.htm

Report Follows

IWRRC Report

Title: *Trace gas flux in riparian buffers along an urban-rural gradient*

Submitted by:
Dr. Pierre-André Jacinthe
Department of Earth Sciences
Indiana University Purdue University Indianapolis (IUPUI)
723 W. Michigan St., SL 122
Indianapolis, IN 46202
Phone: 317-274-7969; fax: 317-274-7966
Email: pjacinth@iupui.edu

Funding Period: March 1, 2006 – February 28, 2007

Problem:
Riparian buffers are located at the interface between terrestrial and aquatic ecosystems. Owing to their landscape position and biogeochemistry, riparian buffers act as natural filters for a variety of water pollutants, and have been shown to be effective in reducing nutrient loadings to adjacent streams and rivers. The water quality protection benefits of these ecosystems are well documented (Hill, 1996; Lowrance et al., 1997; Mitsch et al., 2001; Hickey and Doran, 2004). The protection and restoration of riparian buffers have been recognized as a cost-effective approach to addressing nutrient enrichment problems in aquatic ecosystems (Lowrance et al., 1997; Mitsch et al., 2001).

Riparian ecosystems are flood-prone and are characterized by seasonally-high water tables. These events could lead to O_2 exclusion from soil pore space and development of suboxic conditions at or near the soil surface. These conditions would result in enhanced trace gas production in the most biologically-active upper soil layers, and most specifically could stimulate the production of nitrous oxide (N_2O) via denitrification and methane (CH_4) via methanogenesis. Denitrification is the process whereby, in the absence of O_2, nitrate (NO_3-N) is used as an alternative electron acceptor by soil microbes and is converted into nitrous oxide (N_2O) and dinitrogen (N_2). Methane production occurs via carbon dioxide (CO_2) reduction or via acetate fermentation under anoxic conditions.

The atmospheric trace gases CO_2, N_2O and CH_4 play important roles in the chemistry and energy balance of the earth's atmosphere. Relative to their pre-industrial level, atmospheric concentrations of these greenhouse gases (GHG) have increased 35, 15 and 145 %, respectively during the last 150 years (IPCC, 2001). Their accumulation in the atmosphere has been linked to climate warming (IPCC, 2001). Relative to CO_2, the global warming potentials (GWP) of N_2O and CH_4 are 310 and 21 times greater (IPCC, 2001). In addition, N_2O and CH_4 participate in stratospheric ozone depletion. The transfer of GHG from riparian buffers into the atmosphere is a concern and could offset their water quality improvement benefits. Therefore, information regarding GHG dynamics is an important component of our understanding of these ecosystems.

Several climatic, biological and hydrological factors could affect GHG dynamics in riparian zones. Trace gas fluxes may also be linked to pulses of nutrients input into the surface layer of riparian soils during flooding events and elevated water table. At the present, however, the impact of these factors on gas fluxes in riparian soils is unknown.

Our knowledge of CH_4 dynamics in forest soils is derived almost exclusively from research conducted in upland forests. Due to differences in hydrology and biochemistry, the transfer of this information to riparian ecosystems remains problematic. We therefore do not know whether riparian forests are net CH_4 sources or sinks. Consumption of CH_4 by upland forest soils is widely reported and corresponds to a global CH_4 sink estimated at 30 - 40 Tg CH_4 y^{-1} (Mosier et al., 1997). Research has shown that the oxidation of CH_4 by methanotrophs is very sensitive to environmental pollution (Hanson and Hanson 1996). For example, N fertilization and atmospheric deposition of N have been linked to recent decline in CH_4 oxidation in many temperate forests (Klemedtsson and Klemedtsson, 1997). Several studies in upland forest soils have reported lower rates of CH_4 consumption in urban than in rural forest soils (Castro et al., 1995; Goldman et al., 1995). In a study (Kaye et al., 2004) conducted in the Fort-Collins (Colorado) area, the average rate of CH_4 uptake in urban lawns was half the uptake rate recorded in grassland soils, some 20 km outside the city. Lower rates of CH_4 consumption in urban soils have been attributed to high atmospheric N inputs (Nadim et al., 2001), and deposition of organic and metal pollutants in urban forests (Goldman et al., 1995) creating an environment less than optimal for CH_4-oxidizing microbes. Compared to their upland counterparts, pollution severity is expected to be much greater in urban riparian forests as these ecosystems are affected by both airborne and waterborne pollutants.

There is a need to determine whether for example the removal of NO_3 in riparian zones could result in increased loading of N_2O in the atmosphere. However, despite attempts to come up with ecosystem-specific conversion factors (Groffman et al., 1998), it remains difficult to estimate N_2O emission rates from the amount of NO_3 removed in riparian zones. Part of this difficulty stems from the fact that some of the N_2O produced in riparian soils is reduced to N_2 within the soil profile prior to its transfer into the atmosphere. In a study of N_2O fluxes in several vegetated riparian buffers, Dhondt et al. (2004) reported both net N_2O emission and N_2O uptake with the latter suggesting N_2O conversion to N_2. Several factors control the reduction of N_2O to N_2 including depth of N_2O formation, mineral N availability, residence time and gas diffusivity, redox potential and temperature (Maag and Vinther, 1996; Jacinthe et al., 2000). Research is thus needed to assess the significance of N_2O reduction in buffer zones and elucidate the underlying bio-physical factors.

Research Objectives:

The transfer of greenhouse gases (GHG) from riparian soils into the atmosphere is a concern, but despite this recognition, field data are very limited. The paucity of data is even greater when it comes to urban riparian ecosystems, and to our knowledge, questions related to GHG dynamics in these ecosystems have not been explored in previous studies. In the US, urban development is expected to increase by 79 % during the next 2 decades (Alig et al, 2004) and, consequently urbanization could have measurable impacts on the biogeochemistry of riparian ecosystems. Thus, the objectives of the proposed research are to:

> *(1) investigate the spatial and seasonal variability of trace gas fluxes in riparian zones and identify underlying factors, and*
>
> *(2) assess the impact of urbanization on the dynamics of trace gases in riparian ecosystems.*

Methodology

Description of study sites

A study was conducted at three riparian forest sites in a 100-km transect along the White River in Central Indiana. Site 1 (Lilly Arbor) is located near downtown Indianapolis and includes restored riparian wood lots (trees planted in 1999) and non-forested areas (control) where a mixed vegetation of grasses and shrubs has established. This site is flooded twice a year on average. Site 2 (South West Way Park, IndyParks) is located 15 km south of Indianapolis and includes a mature forest (> 80 y old) experiencing 1-2 flooding events every year and an aggrading forest (45 y old) protected from flooding by a constructed levee. Site 3 (McCormick Creek State Park) is located 70 km south-east of Indianapolis in a rural setting and includes flood-prone (6 times/year) and flood-protected (once every 50-100 y) sections of a mature forest (> 80 y old).

At the Arbor site (site 1), 3 experimental plots (2 wooded and 1 control) were selected. In each plot, two study areas were delimited: one near the river margin (< 10 m) and the other 30-50 m from the river. At each of the other two sites, four study areas were delimited: two in the flood-prone and two in the flood-protected section of the forest.

Monitoring of trace gas fluxes

Trace gas fluxes monitoring began in Fall 2005 at site 1, and in Summer 2006 and the other two sites. Gas flux was monitored by the static soil cover technique with 4 chambers per study area. Chambers consisted of a PVC pipe (H: 30 cm, diam: 15 cm) inserted 5-cm into the ground. During measurement, the PVC pipe was closed with a lid fitted with a gas sampling port. Air samples were taken from inside the chamber headspace 0, 30 and 60 min after closing and stored in pre-evacuated glass vials sealed with gray butyl rubber septa. Within 2-3 days of collection, air samples were analyzed for CO_2, N_2O and CH_4 using a Varian (CP 3800) gas chromatograph fitted with 3 detectors and interfaced with a CombiPal auto-sampler. Trace gas flux was computed using the equation:

$$F = \left(\frac{\Delta C}{\Delta t}\right)\left(\frac{V}{A}\right)k$$

where, $\Delta C/\Delta t$ is the change in gas concentration inside the chamber (mass GHG m^{-3} air min^{-1}), V is the chamber volume (m^3), A is the area circumscribed by the chamber (m^2), and k is the time conversion factor (1440 min d^{-1}). A positive value of F corresponds to a net emission of gas from soil into the atmosphere. Conversely, a negative F value corresponds to a net transfer (uptake) of gas from the atmosphere into the soil.

At the time of sampling, soil temperature was recorded and soil samples (0-15 cm) were collected for determination of gravimetric of gravimetric moisture content.

Principal Findings

Summary

The water quality maintenance function of riparian buffers is well documented, but much less is known regarding the production of the greenhouse gases (GHG) carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in riparian ecosystems. This information is important given the implication of these gases in climate warming and atmospheric chemistry. In order to assess gas fluxes and identify soil processes controlling GHG dynamics in riparian zones, a study was conducted at three riparian sites along the White River in Central Indiana. Study sites included recently-restored (< 8 y) and mature (> 80 y) riparian forests, as well as flood-affected and flood-protected areas. Trace gas fluxes were monitored using the static chamber technique. All three riparian forests were net sink for CH_4 with greater uptake rate (mg CH_4-C m^{-2} d^{-1}) at the older riparian forests (average: -1.84) than at the newly restored site (-0.56). Contrary to expectation, CH_4 uptake rates were generally greater near the river margin than at upland locations (study wide average: -1.8 and -1.2 mg CH_4-C m^{-2} d^{-1}, respectively). Across all sites, CO_2 and N_2O emission was several-fold greater in flood-affected areas near the river margin compared to flood-protected upland locations. These trends are likely related to the preferential deposition of nutrients and coarser materials near the river channel than further upland and underscore the interconnection between fluvial geomorphic processes and GHG dynamics in riparian zones.

Results and Significance

Trace gas fluxes measured during this phase of the study are summarized in the graphs and tables below.

Table 1. Description of the riparian forest sites.

Riparian site	Year of establishment	Location	Description
Lilly Arbor	1999	Urban	- Site includes afforested plots (<7 y old) and shrub/grass dominated plots. - Flooding frequency: twice a year on average. Flooding generally occurs when discharge exceeds 11,500 cfs (325 m^3 s^{-1}).
Southwest Way Park	1961	Suburban	Riverward section: - Hardwood forest > 80 y old. - Flooding frequency: once every 2 y. Flood-protected section: - Cropland until 1961. Hardwood forest ~ 40 y old. - Protected from flooding by a constructed levee.
McCormick Creek State Park	1916	Rural	Riverward section: - Hardwood forest > 80 y old. - Flooding frequency: ~ 6 times a year. Upland section: - Located on 2nd and 3rd terrace - Hardwood forest: > 80 y old. - Flooding frequency: once every 50-100 years.

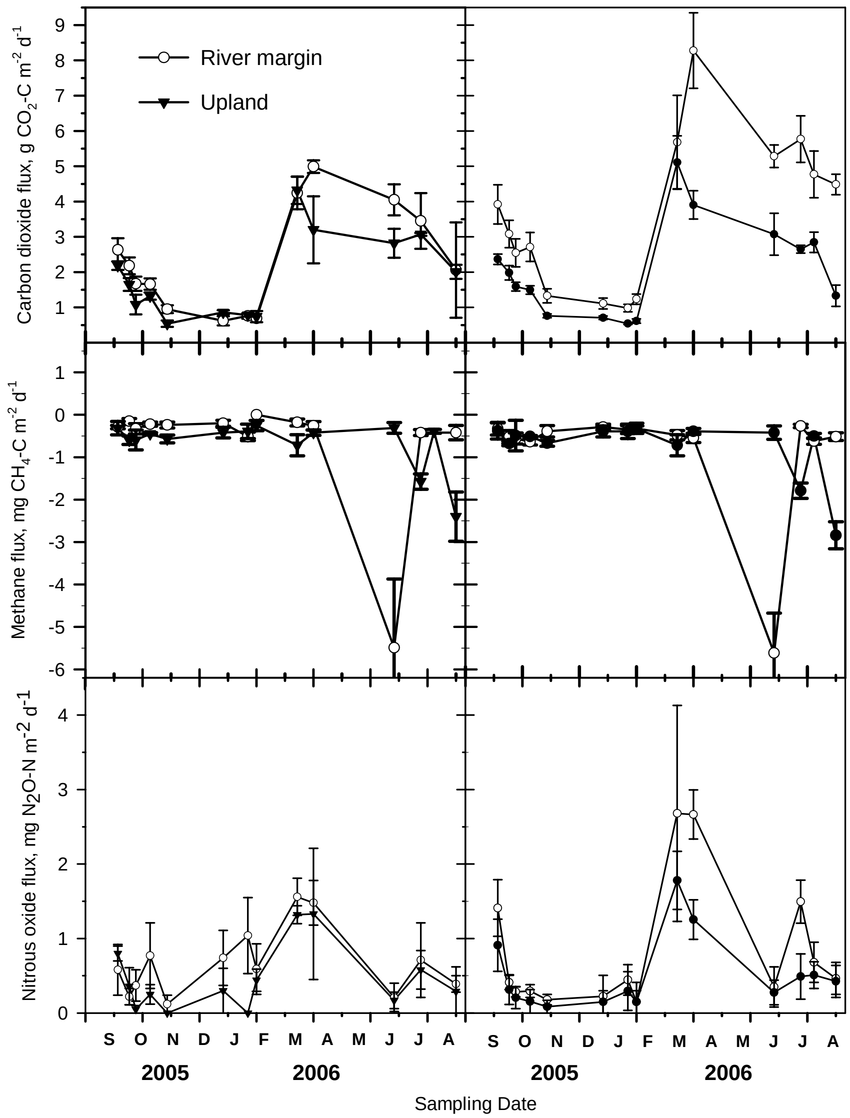

Fig. 1. Daily fluxes of carbon dioxide, methane and nitrous oxide at the Lilly Arbor site during the period September 2005 – October 2006. Graphs in the left and right panels correspond to fluxes measured in the grass/shrub-dominated plots and afforested plots, respectively.

Table 2. Average daily fluxes of greenhouse gases from riparian forest soils along the White River, Central Indiana. Values in parentheses are standard errors of the means.

Riparian sites†	Landscape position	Carbon dioxide	Methane	Nitrous oxide
		g CO_2-C m^{-2} d^{-1}	mg CO_2-C m^{-2} d^{-1}	mg CO_2-C m^{-2} d^{-1}
Lilly Arbor	River margin	3.49 (0.18)	-0.86 (0.1)	0.73 (0.1)
	Upland	1.94 (0.13)	-0.67 (0.1)	0.41 (0.06)
	Site average	2.1(0.14)	-0.56 (0.08)	0.53 (0.06)
Southwest Way Park	River margin	3.43 (0.34)	-2.51 (0.80)	0.68 (0.49)
	Upland	1.72 (0.36)	-1.73 (0.39)	0.29 (0.1)
	Site average	2.58 (0.28)	-2.12 (0.47)	0.51 (0.26)
McCormick's Creek Park	River margin	1.88 (0.37)	-1.92 (0.51)	1.66 (0.60)
	Upland	1.66 (0.18)	-1.20 (0.28)	0.32 (0.10)
	Site average	1.77 (0.71)	-1.56 (0.91)	0.99 (1.4)

† Duration of monitoring period: September 2005 – October 2006 at Arbor; June 2006 – March 2007 at Southwest Way Park; September 2006 – March 2007 at McCormick's Creek Park.

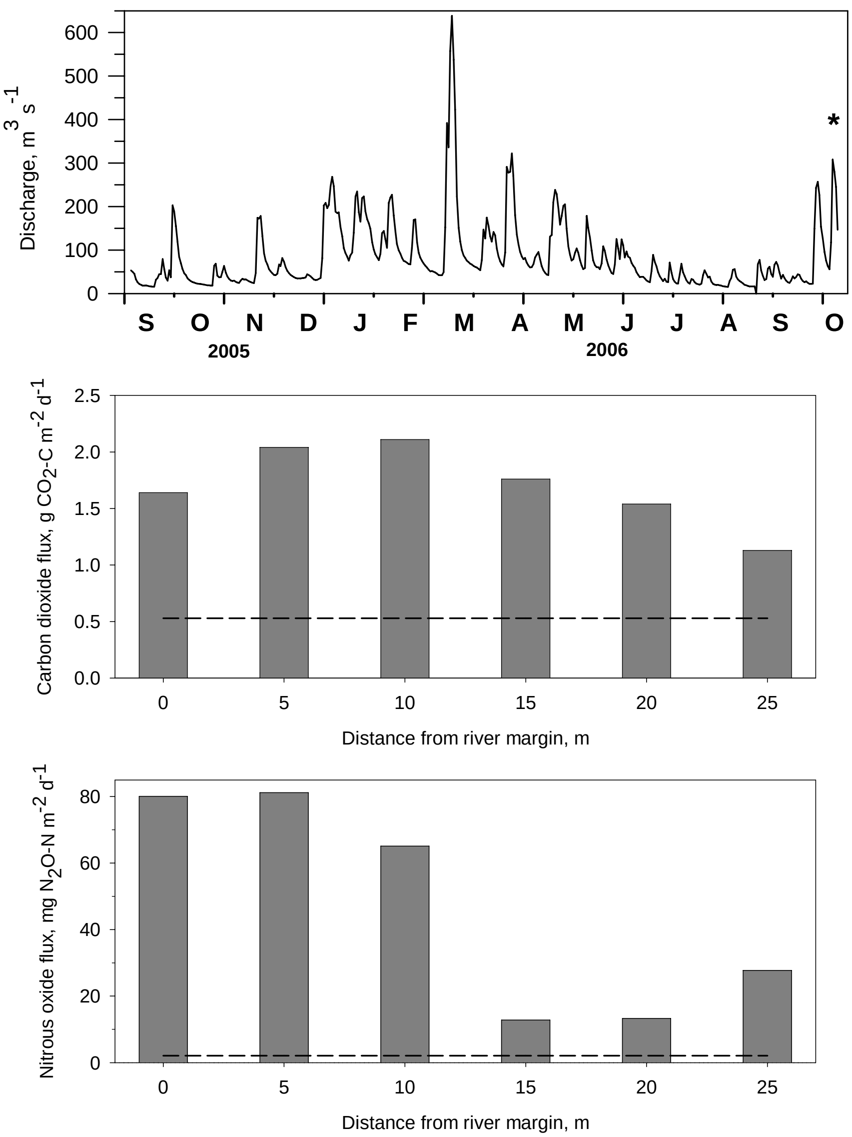

Fig. 2. Carbon dioxide and nitrous oxide fluxes after the flood of October 28, 2006 at the Lilly Arbor site. The dash line represents the non-flood average daily flux.

Major Conclusions

- Soils at the riparian zones are predominantly well drained Inceptisols (Genesee soil series, fluventic eutrudepts) but pockets of Mollisols and Alfisols are also found. Surface soil texture ranges from sandy loam to silt loam near the river channel and to clay loam in the flood-protected areas.

- At the recently-restored (< 8 y) riparian site, CO_2 and N_2O fluxes exhibited similar temporal trends (Fig. 1) and were significantly related (R^2: 0.3, $P < 0.001$). Fluxes were generally higher in early spring and lower in winter. A period of low river discharge (Fig. 2) and warm temperature between June and August 2006 coincided with the period of highest CH_4 uptake. For the other sites, due to the short (< 9 months) duration of the monitoring period, an evaluation of seasonal trend cannot be made at this time.

- Across sites, CO_2 and N_2O fluxes were higher (1.1 -3 fold) near the river margin than at upland locations (Table 2).

- Contrary to expectation, the riparian forest soils were net CH_4 sink regardless of landscape position and flooding history (Table 2). In the summer and fall, CH_4 uptake rates averaged -0.56 and -1.84 mg CH_4-C m^{-2} d^{-1} in the aggrading and mature riparian forests, respectively.

- In addition to temperature and soil properties (texture, porosity) known to control GHG dynamics, preliminary data were collected to document alterations in GHG dynamics following flooding events. Vigorous pulses of N_2O emission (10-40 fold) were recorded in the days following the October 28 flooding event at the Lilly Arbor site (Fig. 2). These results suggest that, if the frequency of flooding events were to increase in the future, riparian forest ecosystems could have a greater impact on regional N_2O budget than their geographical coverage would indicate.

Publications

2 presentations at national meetings

Jacinthe, P.A., L. Tedesco, R.C. Barr. 2006. Soil properties and trace gas fluxes in a newly-restored riparian forest. Annual meeting of the American Society of Agronomy, *Indianapolis. Session 304, Abstract 831*: http://a-c-s.confex.com/crops/2006am/techprogram/P24858.htm

Jacinthe, P.A., J.S. Bills, L. Tedesco, R.C. Barr. 2007. Hydro-climatic events and greenhouse gas dynamics in riparian forests. Fourth USDA Greenhouse Gas Conference, Baltimore. *Session 11, Abstract 213.* http://a-c-s.confex.com/a-c-s/usda/techprogram/P29334.htm

Students

The following students have contributed to this project:

- Graduate Student: Jonathan S. Bills

- Undergraduate Students: Alice J. Enochs, Andrew Schroering, Codi Wieler, April Herman.