

The Effect of Ambient Air Pollution on Respiratory Health of School Children: a Panel Study

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ABSTRACT

Background

Adverse respiratory effects of particulate air pollution have been identified by epidemiological studies. We aimed to examine the health effects of ambient particulate air pollution from wood burning on school-age students in Christchurch, New Zealand, and to explore the utility of urine and exhaled breath condensate biomarkers of exposure in this population.

Methods

A panel study of 93 male students (26 with asthma) living in the boarding house of a metropolitan school was undertaken in the winter of 2004. Indoor and outdoor pollution data was continuously monitored. Longitudinal assessment of lung function (FEV₁ and peak flow) and symptoms were undertaken, with event studies of high pollution on biomarkers of exposure (urinary 1-hydroxypyrene and exhaled breath condensate (EBC) pH and hydrogen peroxide concentration).

Results

No significant effect of pollution could be seen either on lung function or airway inflammation and oxidative stress. Minor increases in respiratory symptoms were associated with high pollution exposure. No significant differences could be identified between healthy students and students with asthma. Urinary 1-hydroxypyrene levels were raised in association with pollution events by comparison with low pollution control days.

Conclusions

There is no significant effect of ambient wood-smoke particulate air pollution on lung function of school-aged students, but a small effect on respiratory symptoms. Urinary 1-hydroxypyrene shows potential as a biomarker of exposure to wood smoke in this

population; however measurement of EBC pH and hydrogen peroxide appears not to be useful for assessment of population health effects of air pollution

INTRODUCTION

Epidemiological studies have established the adverse health effects of particulate air pollution, particularly in relation to cardiac and respiratory effects [1, 2]. However, direct assessment of health impacts of air pollution on individuals presents significant challenges, including the difficulty and expense of accurately assessing personal exposures [3, 4], variation in exposure in home versus school/work and outdoor versus indoor environments and exposure to tobacco smoke. The source of the particulate pollution may also be relevant. The majority of research from the USA and Europe has studied particulate pollution from coal-fired power stations, heavy industry, and diesel engines. However, wood and other organic matter combustion may be significant source of exposure in areas burning solid fuel for domestic heating, such as Canada and the North West USA, and New Zealand.

Direct assessment of lung effects has generally been limited to measurement of peak expiratory flow rate (PEFR) diaries, which, like any self-administered test involving writing down numerical values, may be prone to subjective bias, end-digit preference and auto-correlation. More recently, the availability of electronic downloadable spirometers means detailed lung function assessment in large cohorts can be undertaken easily and cheaply. The spirometers incorporate quality assessment protocols and provide a more objective assessment of lung function. In addition, techniques such as exhaled breath condensate collection now allow non-invasive assessment of airway inflammation, and potentially provide information about oxidative stress responses in the lungs.

The aim of this study was to examine the health effects of ambient particulate air pollution (largely derived from wood-burning for home heating) on school-age children in a panel study design, and to explore the utility of urine and exhaled breath condensate biomarkers of exposure in this population. To reduce exposure variation, and provide accurate assessment of exposure, school children from the boarding houses of a metropolitan private school were studied. Longitudinal studies of lung function effects were undertaken using personal electronic spirometers and symptom diaries, and, after high pollution events, detailed event studies of pollution effects were undertaken using exhaled breath condensate and urine collection.

METHODS

Study site

The study was undertaken in winter 2004 in Christchurch, New Zealand, a city of ~330,000 situated on the east coast of the South Island. Significant air pollution in Christchurch almost invariably occurs in winter, and is characterized by PM₁₀, ~90% of which is PM_{2.5}, that is largely generated by domestic wood-burning open fires and enclosed wood-burners [5]. Mean daily PM₁₀ in central and suburban Christchurch exceeds 50 µg/m³ on ~30 days per year and can reach up to 250 µg/m³ [6]. The health effects of Christchurch air pollution have been the subject of a number of local studies [7-9].

The study was undertaken in the boarding houses at Christ's College, a single-sex private school situated in the central city, but inset into the grounds of Hagley Park, a five km² area of grassland and trees to the immediate west of the CBD but surrounded by the urban area on all sides.

Pollution monitoring

Details of the indoor and outdoor pollution monitoring stations set up at Christ's College are given in Kingham and co-workers [10]. Two pollution monitoring sites were established for this project. The indoor site was a second floor corridor leading to rooms occupied by boarding students. The outdoor site was a courtyard within the school grounds. Indoor and outdoor particulate pollution levels (PM_{10} , $PM_{2.5}$, PM_1) were measured continuously, and expressed as 10 minute averages over a 24 hour period, and 24 hour averages, from midday to midday. Weather data including wind speed, temperature, temperature difference and relative humidity were also continuously collected from the outdoor site and expressed as 10 minute averages.

Participants

The participants were male secondary school students attending the boarding houses of Christ's College, aged between 12 and 18 years. All were healthy non-smokers with no significant medical conditions. A sub-group of students with a previous diagnosis of asthma (defined as "doctor diagnosed asthma ever") were also studied. They were being treated with as-required short-acting beta agonist reliever medication, with some taking regular inhaled corticosteroids (see Results section for details). The regular use of oral corticosteroids was an exclusion criterion. Investigators made no alterations to asthma management and gave no advice about reliever inhaler use during the study.

Prior to commencing the study the health status of the students was assessed by taking a brief medical history. Baseline spirometry and skin prick testing for atopic status were also undertaken.

The study protocol and conduct was approved by the Canterbury Regional Ethics committee. All participants provided written informed consent prior to commencement, and parental approval to participate was also sought.

Lung function assessment

All students were issued with personal downloadable electronic spirometers (Piko-1, Ferraris Respiratory Europe Ltd, Hertford, UK, <http://www.groupferraris.com>) and trained in their use. These spirometers measure Forced Expiratory Volume in 1 second (FEV₁) and peak expiratory flow rate (PEFR) to American Thoracic Society standards [11]. Lung function measurement was undertaken twice daily, in the early morning, and around 6.00 pm, supervised by House Matrons, who were all trained nurses given training in spirometry. Spirometry data were downloaded at least fortnightly by investigators.

Diary cards

All students were issued with daily diary cards to detail respiratory, nasal and eye symptoms. In addition, students with asthma completed diaries detailing asthma symptoms and reliever medication use.

Lung function and diary card data collection occurred during school terms for the duration of the project. When a student was away from the school for more than one

night (weekend and school holidays), diaries and lung function measurements were not undertaken.

High pollution peak assessment

Within 24 hours of two separate high pollution days all participating students underwent a more detailed assessment. The investigators were informed by Environment Canterbury the morning after a high pollution night. The school was contacted, and all participating boys were excused their evening study activities, to be assessed by the investigating team. This involved collection of urine samples for analysis of 1-hydroxypyrene and collection of exhaled breath condensate for measurement of pH and hydrogen peroxide. Baseline assessments were also undertaken at the beginning of the study during a period of low pollution (autumn control) and during the winter, after a 1 week period of low pollution levels (winter control).

Urinary 1-hydroxypyrene levels (1-OHP)

Urine samples were stored at -20°C until analysis. Urinary 1-OHP was quantified using reverse phase high-performance liquid chromatography (HPLC) using a modification of a previously described method [12] as described in Cavanagh and co-workers [13]. The lower limit of detection was 0.23 nmol/L. Hydroxypyrene concentrations were corrected for urinary creatinine to account for hydration status and expressed as μmol 1-OHP/mol creatinine.

Exhaled breath condensate (EBC) collection

Exhaled breath condensate (EBC) was collected using the RTube™ system (Respiratory Research Inc, Charlottesville, USA), using an aluminium cooling tube. The aluminium cooling tube was stored at -20°C for at least 24 hours prior to collection. EBC was collected for ten minutes on each sampling occasion, after rinsing the mouth to reduce saliva contamination. Approximately 2 ml of condensate was collected from each student at each collection.

EBC pH

EBC pH was immediately measured by applying approximately 30 μl of EBC to a pre-calibrated Shindengen ISFET pH meter (model KS701). EBC was not de-gassed prior to pH measurement.

EBC hydrogen peroxide

H_2O_2 was measured in EBC samples using fluorometry with 4-hydroxyphenylacetic acid [14]. Briefly, following the H_2O_2 -dependent conversion of 4-HPAA to the dimer 2,2'-dihydroxybiphenyl-5,5'-diacetate, the fluorescence of each sample was quantified within four hours using a Hitachi F4500 Fluorescence Spectrophotometer (excitation 295 nm, emission 405 nm; slit width 5 nm ex / 10 nm em; PMT voltage 700 V). Linear regression analysis allowed the estimation of the concentration of H_2O_2 in samples based upon a corresponding standard curve. More details of the H_2O_2 assay as used in our laboratory, including validation and optimisation can be found in Brooks and co-workers [15]. The limit of detection of the assay used for these experiments was 3.4 nM H_2O_2 .

Statistics and sample size

For seasonal and event data comparisons of EBC pH, hydrogen peroxide, and 1-OHP concentrations were compared using the non-parametric Friedman's test and Wilcoxon-signed rank tests as appropriate. Readings below the limit of detection for any assay were arbitrarily assigned a value corresponding to 50% of the limit of detection to avoid division by zero in any subsequent calculation. Longitudinal data was cleaned to exclude spurious or physiologically impossible data points by an *a priori* defined protocol. Peak flow and FEV₁ data for each student was expressed as a Z-score relative to the student's mean score over the period of the study. Longitudinal data analysis exploring bivariate association between lung function (Z-scores of PEF_R or FEV₁) or symptom data and pooled air pollution measures (both indoor and outdoor) were conducted using the non-parametric Spearman's' correlation coefficient. Variables showing some association with lung function or symptom data from these analyses were then entered into a mixed-model linear regression analysis to confirm the independent association with lung function or symptoms.

In addition, mean levels of each of the longitudinal outcome variables for each student were calculated within moderate/high (24 hour average > 20 µm/m³ outdoor) pollution days and low pollution days. These levels were compared using Mann-Whitney U tests. Longitudinal data analysis exploring bivariate association between lung function (Z-scores of PEF_R or FEV₁) and pooled air pollution measures on moderate / high pollution (24 hour average > 20 µm/m³ outdoor) days alone were then conducted using the non-parametric Spearman's' correlation coefficient.

The power of the study was of necessity dependant on the number and magnitude of high pollution days during the study period. In addition, limiting the sampling to one

school (to increase exposure validity) placed limitations on potential numbers of students willing/able to participate. Retrospective power analysis was therefore undertaken for lung function scores (expressed as Z-scores) between moderate/high (24 hour average > 20 $\mu\text{m}/\text{m}^3$ outdoor) pollution days and low pollution days. Assuming a 2:1 split in air pollution days, and given $n = 80$ students, the study had an 80% power to detect differences in Z-score values of 0.30 in FEV₁ and 0.27 in PEF_R with $\alpha = 0.05$ (two-tailed). In addition, with 100 time points a correlation between Z-scores and pollution of >0.28 would have been detected as statistically significant i.e. $R^2 > 10\%$.

RESULTS

Students' baseline demographics and lung function

A total of 93 students took part in the study. Twenty-six of these had a doctor diagnosis of asthma. Seventeen of these students used short-acting beta agonists on an as-required basis, while eight students were taking regular inhaler corticosteroids. Mean age of the students at study start was 14 years 5 months (range 12 years 9 months – 17 years 6 months). There were no significant age differences between students with asthma and those without asthma. There was no significant difference in % predicted FEV₁ between asthmatics and non-asthmatics ($97.54\% \pm 2.481$ (mean \pm 1 s.e.) $n=26$, vs $95.49\% \pm 1.635$ $n=57$), though FEV₁/FVC ratio was significantly lower in the asthmatic students (FEV₁/FVC ratio asthma group 0.803 ± 0.013 $n=26$ vs normal group 0.834 ± 0.009 $n=57$, $p=0.05$).

Air pollution

The study was undertaken from the end of March to early September 2004, encompassing autumn and winter. Indoor and outdoor pollution levels are shown in Figure 1 (24 hour average) and Figure 2 (10-min peak). Pollution levels during the winter of 2004 were generally lower than previous years [16], with the majority of high pollution nights occurring during the school vacation period, when data was not being collected. There were however a number of high pollution events where data was collected. Detailed sampling took place after high pollution nights on June 24 and July 21. The 24-hour average outside PM₁₀ level recorded at the school on those dates was 43 µg/m³ and 72 µg/m³ respectively. Peak outdoor PM₁₀ levels for a 10-minute period reached 105 µg/m³ and 257 µg/m³ respectively. The majority of PM₁₀ pollution was in the PM_{2.5} range, and indoor pollution levels were similar to outdoor. Occasional very high pollution peaks were identified indoors. These tended to be in the PM₁₀ range, rather than PM_{2.5}, and probably represented resuspension events due to activity in corridors. On average, pollution levels measured at the school were 22.5% lower than those measured at the central Environment Canterbury monitoring station.

Urinary 1-OHP levels

Urine 1-OHP levels are shown in Figure 3. Urine 1-OHP levels were significantly higher on the high pollution days compared to both low pollution control days. Median (25-75% range, number of sample analysed) 1-OHP levels corrected for creatinine were: Autumn control 0.0195 (0.009-0.036, n=88) µmol OHP/mol creatinine; Winter control 0.025 (0.013-0.038, n=77) µmol OHP/mol creatinine; Pollution day 1 0.043 (0.030-0.073, n=79) µmol OHP/mol creatinine; Pollution day 2 0.042 (0.022-0.064, n=73); p<0.0001 for all comparisons of high pollution days vs

controls. Differences in 1-OHP levels between the two control days did not reach statistical significance. Similarly, the 1-OHP levels on the two high pollution days were not significantly different.

EBC pH

EBC pH readings are shown in Figure 4. There was a broad range of pH readings on all sampling days. pH differences between autumn and winter controls reached statistical significance, and pH at the first high pollution day was significantly higher than the second study day, and the winter control day, but not the autumn control day. There was no independent effect in students with asthma in comparison with healthy students.

EBC hydrogen peroxide

EBC H₂O₂ readings are shown in Figure 5. Detectable hydrogen peroxide was present in most samples. There was no difference in measured H₂O₂ between any of the sampling days, either control or high pollution. There was also no difference in proportions of samples with detectable H₂O₂. There was no independent effect of asthma in comparison with healthy subjects. There was no significant correlation between EBC levels of hydrogen peroxide, and pH, and no correlation with either of these measurements and urinary 1-OHP.

Lung function data.

FEV₁ data was available for a median of 129.5 time points per student (Range 4-189). PEF data was available for a median of 128 time points (Range 2-186). Univariate analysis identified a number of biologically plausible correlations between lung

function data and PM₁₀ levels which reached statistical significance. There was a significant correlation between morning FEV₁ and 24 hour average outdoor air pollution levels the previous day (Spearman's rho -0.201, p=0.034). When analysing for the presence of asthma, asthmatic subjects showed correlations between FEV₁ and 24 hour average outdoor air pollution levels which just failed to reach statistical significance (Spearman's rho -0.187, p=0.06), while non-asthmatic subjects showed no significant correlations. There was no significant correlation between peak PM₁₀ levels and lung function in either asthmatics or non-asthmatics.

When multivariate analysis was undertaken, using six dependant lung function variables, no pollution variable was retained in a regression model, with only minor temperature effects being retained. Similarly when asthmatics were studied separately, no independent effect of air pollution could be identified in a multivariate analysis model.

When comparing median morning FEV₁ between moderate / high pollution days (>20 µg/m³) and low pollution days, students with asthma demonstrated lower readings on high pollution days (p=0.043). No effect was seen in non-asthmatic students. However, studying moderate / high pollution days only, no significant correlation between lung function and pollution level could be detected, either in asthmatics or normal students.

Diary card and symptom data

Symptom score data was available for a median of 119 time points (Range 109-119).

A number of biologically plausible associations were identified between symptoms

and both indoor and outdoor air pollution levels. The proportion of students reporting cough and ear, nose and throat symptoms increased with increasing indoor air pollution the previous day. Maximum outdoor air pollution levels the same day were associated with increasing proportion of students reporting cough. The effect of maximum outdoor air pollution remained significant when multivariate analysis was undertaken, and remained in the model, while weather effects were excluded by the model. The effect size however was small, with a change in PM₁₀ of 50 µg/m³ being associated with a 1.5% increase in proportions of children reporting cough (equivalent to one extra report of cough on high pollution days in this cohort).

DISCUSSION

This study describes comprehensive pollution and respiratory health monitoring of a panel of students at the boarding house of a metropolitan school. Urinary 1-OHP levels were raised in association with pollution events, but no significant effect of pollution could be seen either on lung function or airway inflammation and oxidative stress. Minor increases in respiratory symptoms were associated with high pollution exposure, but no other significant differences in lung function or biomarkers of airway inflammation could be identified between healthy students and students with asthma.

The importance of accurate assessment of pollution exposure in health effects studies has been recognised since at least the early 1980's. The most accurate measurement tool, personal exposure monitoring, is expensive and logistically difficult, and does not easily lend itself to panel studies involving large numbers of subjects, particularly children. Differing exposures at home compared to work / school also decreases the accuracy of exposure assessment. The effect of cigarette exposure, both personal and

via passive smoking, acts as a confounder for the assessment of health effects of air pollution. This study attempted to circumvent these issues by studying schoolchildren living and studying in the same, smoke-free environment. Other potential confounders such as dietary variation might also be expected to be reduced by central institutional catering. The close relationship between indoor and outdoor air pollution levels compares favourably with similar studies which have used personal exposure monitoring [17]. The difference in pollution levels measured at the school, compared with the central monitoring station argues strongly against relying solely on central monitoring for exposure assessment.

Urinary 1-hydroxypyrene has previously been proposed as a biomarker of exposure to polycyclic aromatic hydrocarbons (PAHs) [18]. Early studies primarily focussed on occupational exposure to PAHs, while recent studies have investigated environmental exposure to PAHs, including via vehicle emissions or indoor sources such as coal burning stoves and tobacco smoke [19, 20]. The current study is the first to investigate the utility of 1-OHP for assessing environmental exposure to PAHs suggested to be primarily derived from wood-burning for home-heating. The potential use of 1-OHP as a biomarker of pollution exposure in this population is explored in more detail elsewhere [13].

No significant independent effect of air pollution on lung function was detected in this population, either in those children with asthma, or healthy children. The power of the study may have been reduced by relatively low pollution levels during the winter of 2004, especially during the school terms, when children were collecting lung function data. A systematic review of air pollution and panel studies in children has however

suggested publication bias towards adverse effects of particulate air pollution on lung function and lower respiratory symptoms [21].

This study also demonstrated small but statistically significant effects of pollution on ear, nose and throat symptoms in this population. This is consistent with previous studies of wood-smoke air pollution [8].

More recently, researchers have explored the utility of studying airway inflammation in the context of pollution exposure. A number of studies have recently been published describing the relationship of exhaled nitric oxide levels to pollution exposure [22, 23]. Nitric oxide was not measured in this current study, due to the lack of portable equipment in 2004. However, exhaled breath condensate has been proposed as another simple non-invasive tool for measurement of airway inflammation [24]. Whilst nitric oxide measurement only provides information about eosinophilic airway inflammation, other markers of airway inflammation such as pH and hydrogen peroxide can be studied in EBC. EBC pH has been shown to vary between individuals and in respiratory conditions such as bronchial asthma, bronchiectasis and chronic obstructive pulmonary disease [25], and EBC H₂O₂ is increased in a number of inflammatory conditions such as asthma, chronic obstructive pulmonary disease and community acquired pneumonia [26-29].

No demonstrable effect of pollution on EBC pH or H₂O₂ was demonstrated in this study, either in healthy children, or children with asthma. The ranges of results for both tests were broad, with no correlations between EBC levels of hydrogen peroxide, and pH, and no correlation with either of these measurements and urine 1-OHP. This

suggests that using the current collection and analysis methods, EBC analysis for pH and H₂O₂ is not suitable for use as a biomarker of lung inflammation due to air pollution exposure.

In summary, we detected no significant effect of ambient wood-smoke particulate air pollution on lung function of school-aged male students, but a small effect on cough. Urinary 1-OHP shows potential as a biomarker of exposure to PAHs in wood smoke in this population; however measurement of EBC pH and hydrogen peroxide appears not to be useful for assessment of population health effects of air pollution.

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AUTHORS CONTRIBUTIONS

All authors made substantial contributions to the conception and design of the study, and the acquisition of data. All have been involved in the drafting and revision of the

manuscript. ME was principal investigator for the study, and took overall responsibility for the design, implementation and analysis of the study. SK and TA coordinated the pollution monitoring and analysis and contributed to event study assessments; JC, LB, and KT coordinated the collection and analysis of the urinary 1-OHP samples and contributed to event study assessments; RD, TH, SM, FM, and JC coordinated the diary card and spirometry data acquisition, and coordinated the event study assessments. WB undertook the EBC hydrogen peroxide analysis and contributed to event study assessments. CF was the biostatistician for the study.

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LEGENDS

Figure 1: Indoor (open triangle) and outdoor (closed triangle) 24 hour mean PM₁₀ levels. The school holiday period, when no biological data was collected, is marked. Detailed event studies occurred after high pollution nights marked with arrows. The New Zealand National Environmental Standard cut-off for high pollution days is marked at 50 µg/m³

Figure 2: Indoor (open triangle) and outdoor (closed triangle) 10-minute peak PM₁₀ levels. The school holiday period, when no biological data was collected, is marked. Detailed event studies occurred after high pollution nights marked with arrows

Figure 3: Urinary 1-hydroxypyrene levels (adjusted for creatinine) on the control and high pollution assessment days. * p<0.0001 for all differences between high pollution days and controls

Figure 4: Exhaled breath condensate pH levels on the control and high pollution assessment days

Figure 5: Exhaled breath condensate H₂O₂ levels on the control and high pollution assessment days

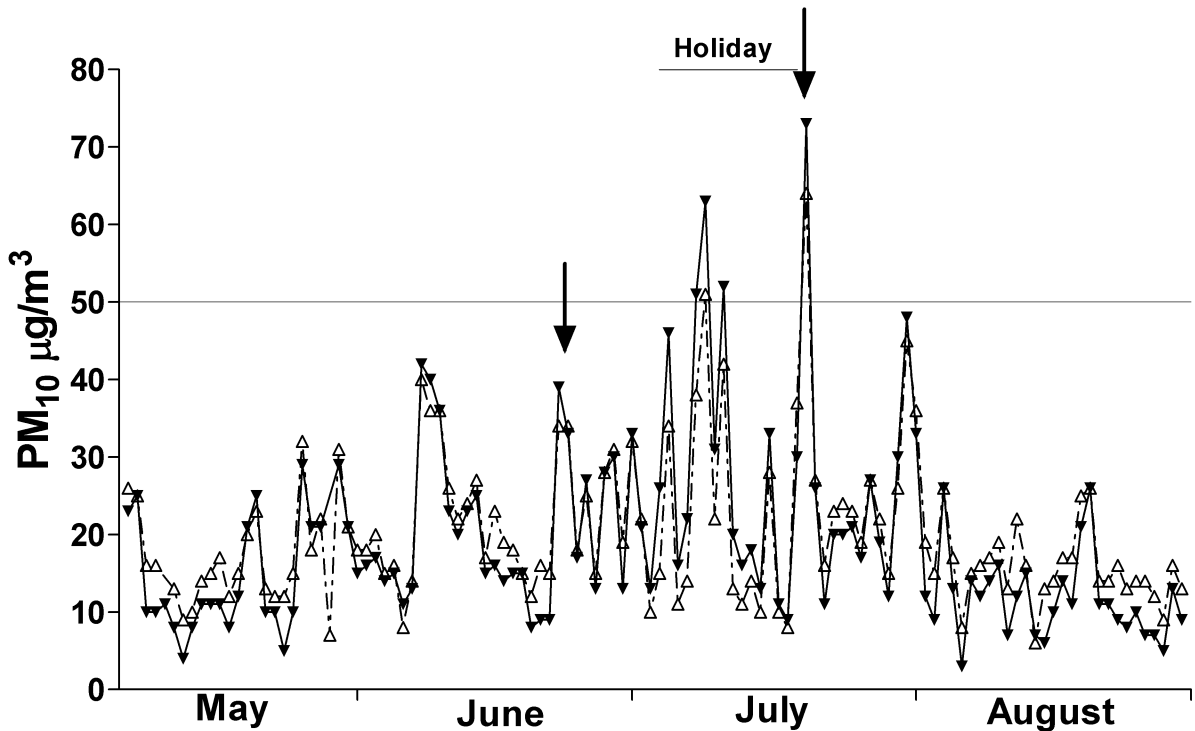


Figure 1

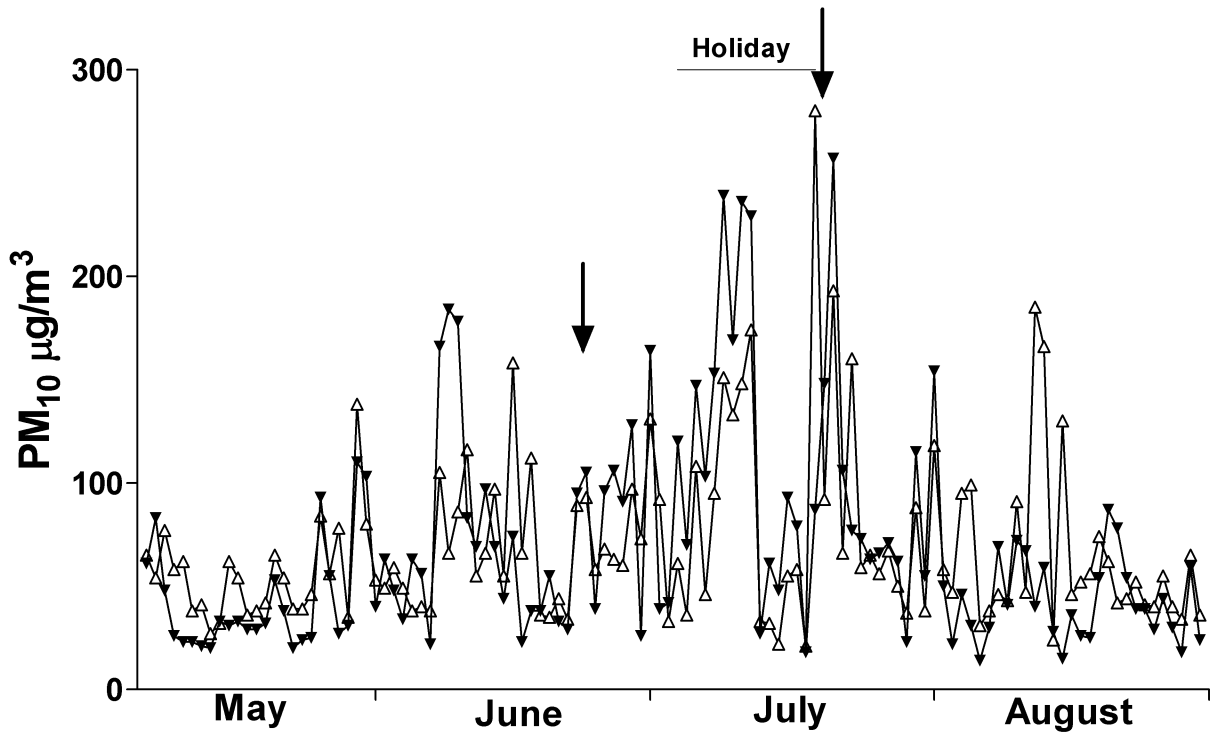


Figure 2

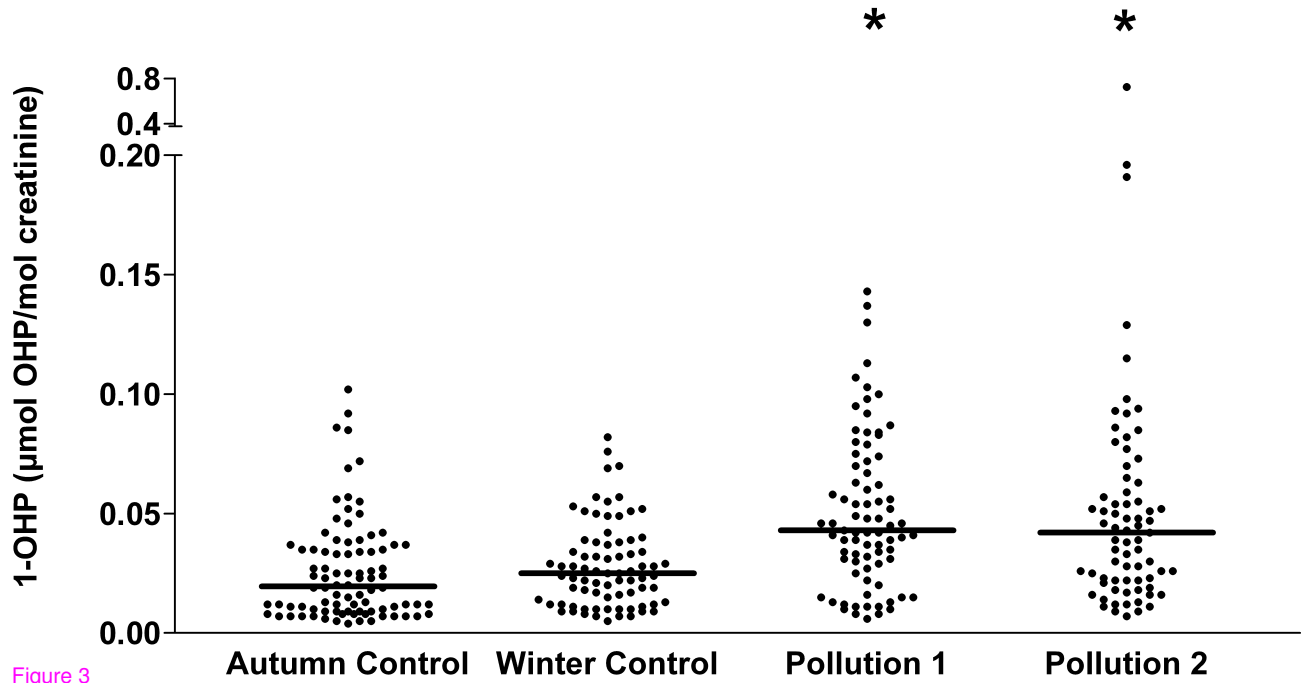


Figure 3

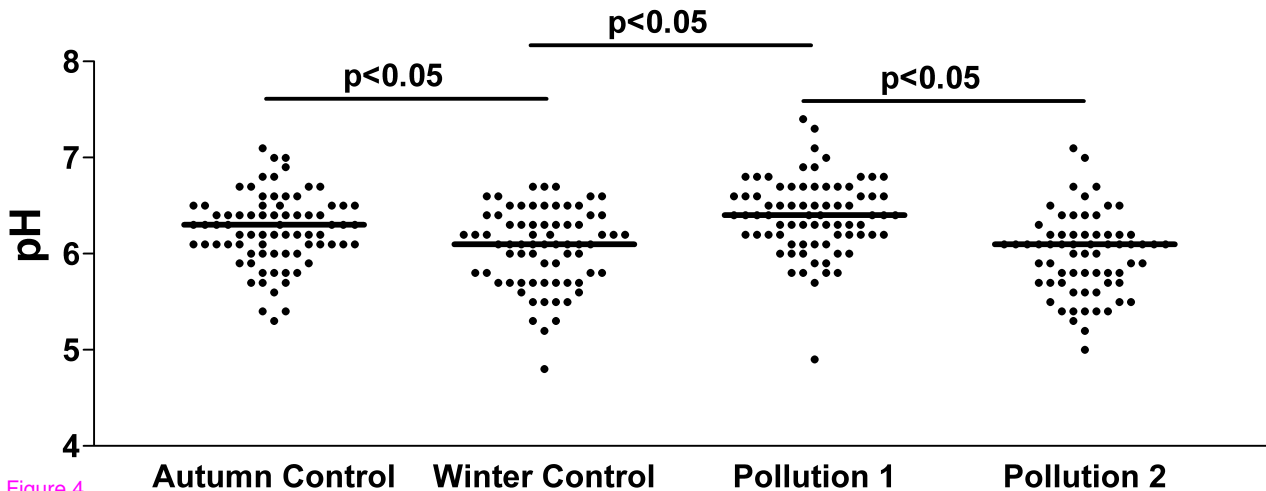


Figure 4

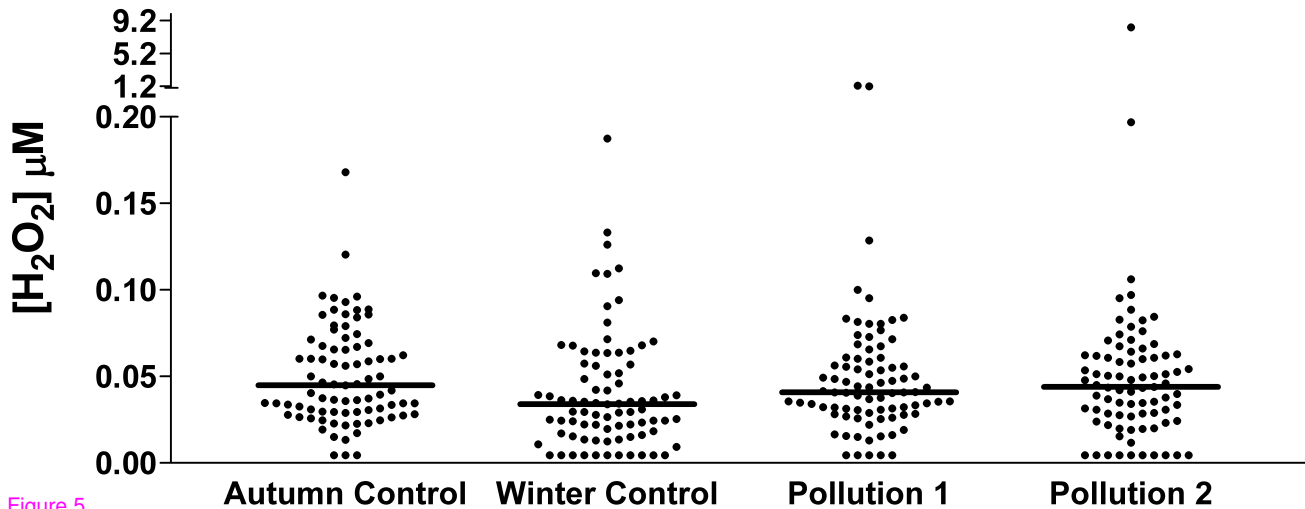


Figure 5

Additional files provided with this submission:

Additional file 1: stoten9713.pdf, 291K

<http://www.ehjournal.net/imedia/1744484332133466/supp1.pdf>