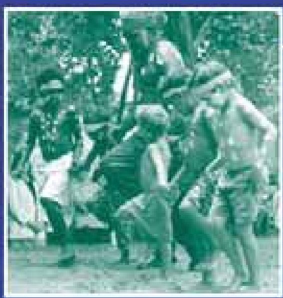
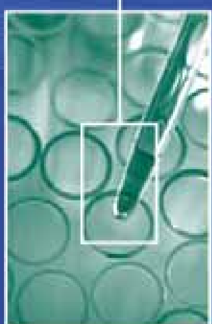
Environmental Health

The Journal of the Australian Institute of Environmental Health



...linking the science and practice of Environmental Health



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Environmental Health is a quarterly, international, peer-reviewed journal designed to publish articles on a range of issues influencing environmental health. The Journal aims to provide a link between the science and practice of environmental health, with a particular emphasis on Australia and the Asia-Pacific Region.

The Journal publishes articles on research and theory, policy reports and analyses, case studies of professional practice initiatives, changes in legislation and regulations and their implications, global influences in environmental health, and book reviews. Special Issues of Conference Proceedings or on themes of particular interest, and review articles will also be published.

The Journal recognises the diversity of issues addressed in the environmental health field, and seeks to provide a forum for scientists and practitioners from a range of disciplines. Environmental Health covers the interaction between the natural, built and social environment and human health, including ecosystem health and sustainable development, the identification, assessment and control of occupational hazards, communicable disease control and prevention, and the general risk assessment and management of environmental health hazards.

Aims

- To provide a link between the science and practice of environmental health, with a particular emphasis on Australia and the Asia-Pacific Region
- To promote the standing and visibility of environmental health
- To provide a forum for discussion and information exchange
- To support and inform critical discussion on environmental health in relation to Australia's diverse society
- To support and inform critical discussion on environmental health in relation to Australia's Aboriginal and Torres Strait Islander communities
- To promote quality improvement and best practice in all areas of environmental health
- To encourage contributions from students

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...linking the science and practice of environmental health

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Call for Papers

The Journal is seeking papers for publication.

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Guest Editorials address topics of current interest. These may include Reports on current research, policy or practice issues, or on Symposia or Conferences. Editorials should be approximately 700 words in length.

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Short reports of topical interest should be approximately 1500 words. Book reviews should be approximately 700 words and Review Articles should not exceed 3000 words in length.

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Welcome to Issue 2 of 2007. This issue includes a range of topics under examination. Main et al. report on the investigation of a cluster of reported cases of Human Psittacosis in Newcastle, Australia. Psittacosis can be transmitted from birds to humans via inhalation. This paper explores the investigation of a pet store by Environmental Health Officers from the Hunter New England Population Health Unit and local Council. Their environmental health risk assessment used a customised investigation tool to identify a number of hazards and poor practices at the store. These included staff not using personal protective equipment when cleaning, inadequate ventilation, lack of quarantine procedures, and accumulation of faecal waste in cages among other concerns. The authors highlight the need for improved interagency collaboration and research, strengthening of legislation and a standardised approach to assist in reducing the risk of future disease outbreaks associated with pet stores.

Khan, Parton and Doran conducted a clinical event survey to ascertain the cost of particulate air pollution in Armidale, in Northern New South Wales. A survey of GPs was used to examine the health impacts and estimate the economic costs associated with morbidity caused by particulate pollution from domestic wood smoke. The survey revealed that a high number of visits to GPs regarding respiratory conditions were due to particulate air pollution. The daily economic cost to the town from these cases was calculated and, subsequently, revealed a need for rural towns to take into account the health impacts of wood heating in development and planning decisions.

Jeong and Chang explore the issue of environmental health and sustainability, using South Korea as a case study to estimate optimum population for sustainable development. A multiple regression analysis of ten-year time series data was used for fifty-five environmental variables including population. Survey results revealed that environmental budget and clean energy supplies are important in determining optimum population, while different levels are estimated depending on the environmental variables. Although results in this study are based on a limited number of parameters, further development of this model may prove useful for future policies and management of sustainable development to prevent ecological and human impacts from over-population.

Legionella continues to present environmental health issues in Australia. Critchley and Bentham present an overview on *Legionella* and protozoa in cooling towers, including environmental factors influencing microbial colonisation, the Australian perspective and the link between protozoa and the survival of *Legionella*. The implications for public health and utilisation of chemical control are also explored in this article. The authors propose that the presence of protozoa is an important factor to consider when developing cooling tower health risk management strategies. Lau and Harte also examine *Legionella*, however, their study focuses on public water features in New Zealand rather than cooling towers. Water samples were collected from seven sites in Wellington, including a waterfall, water fountains and ponds (including a duckpond). Samples were tested for levels of free and total available chlorine and the presence or absence of *Legionella* bacteria. The presence of positive samples indicate that public water features should be regularly cleaned to reduce health risks to the community.

Jordan, Dunn and Verrinder report on and discuss the development of a multi-functional educational and training module in the evaluation of Environmental Health Services. The module was developed in response to the need for strengthening evidence based practice in environmental health activities. This report covers the development processes of the module including stakeholder consultation, through to the evaluation of the module.

Book Reviews

Tenkate again provides some interesting reviews on two environmental health texts. Rodrick's first issue of *Calculated Risks: The Toxicity and Human Health Risks of Chemicals in Our Environment* won an 'Honorable Mentions' Award from the American Medical Writers Association. Tenkate will let you know if the second edition (2007) lives up to its predecessors' reputation. Secondly, we are introduced to *Public Health Practice in Australia: The Organised Effort* by Lin, Smith and Fawkes (2007). Find out why Tenkate is compelled to use the three 'C' words in this review: completeness, clarity and consistency.

Local government environmental health workforce planning was the subject of a national summit convened by the Institute in Brisbane on 2 and 3 July. Over 80 participants from government, universities and peak bodies attended the Summit. A report on the Summit proceedings will be available shortly, however, workforce planning will continue to be a major focus of the Institute and will have prominence at the International Federation of Environmental Health Congress in May 2008. Consideration is being given to publishing a special issue of the Journal dealing with workforce at the end of this year, or just prior to the Congress. Contributions are being sought for this special issue.

The next issue of the journal will be a special issue on climate change with a guest editorial from environmental health academic and researcher, Dr Thomas Tenkate.

As always we are seeking contributions to the Journal. There has been a particular shortage of contributions from practitioners and their experiences in delivering environmental health services to the community. These experiences need to be told so we can continue to learn and develop our practice.

Jim Smith

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Cost of Particulate Air Pollution in Armidale: A Clinical Event Survey

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The objective of the research reported in this paper was to assess the health impacts and economic costs of particulate pollution caused by woodsmoke from domestic heating in a rural town. Using a survey of general practitioners (GPs), the number of respiratory cases per day was related to the level of particulate ($PM_{2.5}$) pollution. Poisson regression was used, with the number of GP visits for respiratory treatment the dependent variable and level of pollution, temperature and the location of the GP surgery as explanatory variables. This provided an estimate of the number of cases caused by woodsmoke pollution. The economic cost was then obtained by multiplying this number of cases by the cost per patient. The results show that particulate air pollution caused by woodsmoke from domestic heating does result in patients presenting with respiratory illness. Approximately 38% of total respiratory visits to GP surgeries were due to particulate air pollution. The daily economic cost of respiratory symptoms in the town due to this pollution was estimated to be $1666. The work has two major implications. First, it presents a method of using GP data to estimate the level of morbidity and cost associated with particulate air pollution. Second, it shows that there is a need in rural towns to consider the health impacts of planning decisions related to wood heating.

Key words: *Pollution; Woodsmoke; Wood Heaters; Rural Town; Public Health Implications*

The convergence of epidemiological results suggests a clear role of particulates, especially fine particulates (less than 2.5 microns in aerodynamic diameter), in triggering a number of adverse health effects. These include increased rates of lower respiratory symptoms, upper respiratory symptoms, asthma attacks, a decrease in lung function; and increased mortality. There is often a consequent increase in the use of health care services typically measured by hospital admissions or emergency room visits (Abramson & Beer 1998; Dockery et al.1993; Ostro 1987; Ostro & Rothschild 1989; Pope & Dockery 2006; Pope et al.1995). As well as such short-term impacts, longer-term health effects such as an increase in cardiovascular disease have been observed (Künzli et al. 2005).

The health effects of particulate pollution have been associated with different particulate size fractions. Fine particulates, such as those from fossil fuel combustion, are likely to be the most hazardous, because they are inhaled deep into the lungs, settling in areas where the body's natural clearance mechanisms are unable to remove them (Larson & Koening 1994). The National Environment Protection Council (NEPC) has defined National Environment Protection Measures (NEPMs) for PM_{10} and $PM_{2.5}$ particulates (NEPC 2003), but no threshold concentration of either PM_{10} or $PM_{2.5}$ below which cases would not occur has been observed. Detrimental health effects have been observed at low levels of concentration (Baruch 1998; Morgan et al. 2003; Pearce & Crowards 1996; Samoli et al. 2005; Schwartz et al. 1994; World Health Organization [WHO] 1995).

Woodsmoke consists almost entirely of fine particles ($PM_{2.5}$). Emissions from domestic wood heaters are a potential harmful source of air pollution in Australia. The adverse health effects of woodsmoke pollution have been studied in the United States (US) and other countries (Larson & Koening 1994), but despite substantial quantities of pollution generated by wood burning, little research into the health effects has been carried out in Australia (New South Wales Department of Health 2003).

Armidale, located in Northern New South Wales, Australia, is an ideal place to examine the potential health effects of woodsmoke, since air pollution in Armidale consists almost entirely of emissions from wood heaters (Roberts & Lin 1998). Low temperatures in winter, together with relatively cheap wood fuel, encourage people to operate wood heaters. As much as two tonnes of particulates can be emitted into the air over Armidale on a very cold night (Armidale Dumaresq Council [ADC] 2003; Wall 1997). Incomplete combustion results in increased quantities of pollutants, which become trapped in Armidale's frequent temperature inversions.

This study examined whether there is a relationship between particulate air pollution and the number of patients with respiratory symptoms visiting local GPs' surgeries. The main objective of the study was to estimate the effects of particulate air pollution in Armidale in terms of health status and economic cost. Based on this information the public health implications are then assessed.

Method

Overall approach

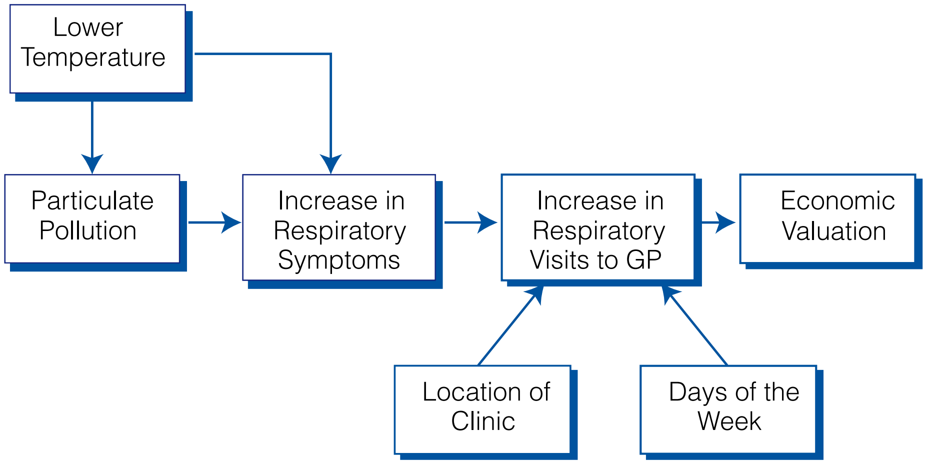
The method adopted was to estimate the statistical relationship between number of respiratory cases (the dependent variable) and pollution, minimum temperature and surgery location (the explanatory variables). The morbidity data were measured as GP visits. These data were collected from GP surgeries. The $PM_{2.5}$ particulate pollution data were collected from nephelometer readings by the Armidale Air Quality Group (AAQG) and the ADC, and the weather data were provided by the Bureau of Meteorology.

Many studies have used data such as hospital admission or emergency room visits to examine respiratory morbidity (Ponka et al. 1991; Pope 1989, 1991). However, hospital data require large populations in order to identify relationships between air pollution and respiratory illness. Because Armidale is a small town (population 22,000), it was more appropriate to use local GP data to identify such a relationship. GP data might also be usefully employed in an urban setting.

There are direct and indirect links between lower temperatures and increases in respiratory illnesses (Diaz et al. 2004). Temperature certainly plays a primary role in the generation of particulate air pollution, since low temperatures encourage people to use their wood heaters, leading to increased particulate pollution. Lower temperatures might also directly trigger an increase in respiratory illness or asthma attacks (Diaz et al. 2004; Verlato 2002; Weiland et al. 2004). This might mean that heating, even using a wood heater, could provide health benefits to some individuals.

The day of the week might also be important in establishing the pattern of respiratory consultations, since GP surgeries are closed on weekends. Any increase in respiratory patients in GP surgeries might, in part, be confounded by a 'weekend effect'. In particular, we could expect increases on Mondays and Fridays. Further, the location of GP surgeries might have an important influence on increases in respiratory patient visits. Figure 1 is a schematic representation of our study that shows the impact of temperature on particulate pollution causing physical effects and which incur economic costs.

Figure 1: A schematic outline of the key variables



Thus, the factors of minimum temperature, particulate air pollution, location of the GP surgery and day of the week, were incorporated as explanatory variables in the model for examining clinical events. The essential feature of the analysis in this paper is the disaggregation of the total number of respiratory patients into those caused by air pollution and those due to all other causes. The estimated number due to air pollution was then multiplied by the estimated cost.

The analytical method was Poisson regression (Fleiss et al. 2003). In conventional regression analysis, we have a *continuous* (dependent) variable and we seek to explain its variation. This is done by postulating that the value the variable takes is determined to a large extent by some other (regressor) variables. The regression model shows how the average of the dependent variable is determined by the values of regressor (or explanatory) variables. Poisson regression is the analogous statistical tool for the analysis of *count data*.

In this context, the variable we seek to explain is the number of patients per day who visit surgeries with respiratory complaints. We assume that this number is determined, in part, by the value of particulate air pollution, the minimum temperature, and the particular surgery chosen. Variables that measure these three types of determinants become the regressor variables, denoted collectively by X. The average number of respiratory patients, denoted as n_r, is the dependent variable.

The Poisson regression model relates the dependent variable to the regressor variables through the function:

$$n_r = \exp(X'\beta) \qquad (1)$$

where exp(.) is the exponential function, and $X'\beta$ is a linear combination of the regressor variables (Fleiss et al. 2003). In particular, we assume that

$$X'\beta = \beta_0 + \beta_1 x + \delta_1 C_1 + ... + \delta_5 C_5 + \varphi_0 T + \varphi_1 T_1 + ... + \varphi_4 T_4, \qquad (2)$$

where x is particulate air pollution lagged 2 days, C_1 to C_5 are dummy variables relating to the five surgeries other than the base surgery (surgery 0), T is the minimum temperature and T_1 to T_4 are the minimum temperatures lagged one to 4 days, respectively. The model of equation 2 was then used to summarise the impact of $PM_{2.5}$ particulate pollution and weather on the number of respiratory cases.

Respiratory symptoms data

Respiratory symptom data were collected from Armidale General Practitioner Surgeries. There is a total of 26 GPs in Armidale, practising in eight surgeries in the city. The number of GPs per surgery varies from 1 to 6 with some working only part-time. All 26 GPs were contacted, and 15 GPs from six surgeries agreed to participate in the study.

The GPs were asked to record the diagnoses observing the following classification: (a) total visits (respiratory and non-respiratory) for that day; (b) respiratory visits due to acute upper respiratory symptoms; (c) respiratory visits due to acute lower respiratory symptoms; (d) respiratory visits due to chronic lower respiratory symptoms; (e) visits due to asthma; and (f) visits due to respiratory infection. For each day the number of medical visits with each diagnosis was totalled across surgeries. Data were collected during the period 1 June to 20 August, a total of 12 weeks, excluding weekends.

In the study period, a total of 9481 patients were seen by the GPs, of whom 1370 persons presented with respiratory illness, which was 14.4% of the total number of GP visits.

Particulate air pollution and weather data

Particulate air pollution data for the winter of 1999 (June to August) were obtained from the Armidale Air Quality Group (AAQG) and the ADC. The data from the AAQG's data were measured in the East Armidale residential area. The ADC nephelometer readings were taken at the council chamber in the Central Business District (CBD) area, which is a relatively chimney-free area. Usually, the air pollution reading at ADC is about half the AAQG's reading. Air pollution data were collected for both the daily (24-hours) mean concentration and daily maximum (1-hour) concentration. The AAQG used a Radiance Research Reeve Analytical Orthogonal nephelometer calibrated for $PM_{2.5}$, and a conversion ratio of one scattering coefficient unit to 20 µg/m^3 of $PM_{2.5}$ was applied (Robinson et al. 1998). As explained below, this became our principal source of pollution data.

Weather data for Armidale were obtained from the Bureau of Meteorology-NSW regional office. The Bureau of Meteorology station is located at the Armidale Airport, 1084m above sea level and at the western end of the valley, about five kilometres from the CBD. The weather variable of interest in the present study was minimum temperature. As discussed above this was expected to impact directly on the number of respiratory cases, and indirectly though its impact on the

Table 1: Summary statistics: Air pollution and temperature data 1 June to 20 August 1999

	Mean	Std. deviation	Minimum	Maximum
Daily Minimum temperature (°C)	0.98	4.48	-8.00	9.00
Daily average particulate pollution (AAQG) $PM_{2.5}$ (µg/m^3)	31.82	31.39	1.71	140.46
Daily average particulate pollution (ADC) $PM_{2.5}$ (µg/m^3)	13.93	12.14	1.26	44.82
Daily maximum particulate pollution (AAQG) $PM_{2.5}$ (µg/m^3)	96.18	83.76	3.17	325.94
Daily maximum particulate pollution (ADC) $PM_{2.5}$ (µg/m^3)	46.08	44.50	2.25	186.75
Daily average particulate pollution (ADC +AAQG) $PM_{2.5}$ (µg/m^3)	22.90	21.21	1.98	86.77
Daily maximum particulate pollution (ADC +AAQG) $PM_{2.5}$ (µg/m^3)	21.13	61.32	3.17	215.91

AAQG= Armidale Air Quality Group, ADC= Armidale Dumaresq Council

Table 2: Correlation between respiratory visits and air pollution

	Proportion of respiratory visits	Total number of visits
Ave.AAQG-2-day lag	0.227 (.000)	0.252 (.000)
Max.AAQG, 2-day lag	0.192 (.001)	0.222 (.000)
Ave.ADC, 2-day lag	0.208 (.000)	0.207 (.000)
Max.ADC, 2-day lag	0.163 (.005)	0.142 (.015)
Ave.(AAQG+ADC), 2-day lag	0.299 (.000)	0.248 (.000)
Max.(AAQG+ADC), 2-day lag	0.191 (.001)	0.206 (.000)

amount of wood burning and hence $PM_{2.5}$ levels. Table 1 provides the general descriptive statistics of the 12-week study period.

Results & Discussion

Initial results

Particulate air pollution was found to be negatively related to temperature, which supports the proposition that wood was an important source of heating. The strong correlation between AAQG and ADC data (correlation coefficient = 0.86), indicated that one or other should be used in the regression analysis, but not both as this would introduce a multicollinearity problem. Given its nephelometer location in a residential area, the AAQG data source was considered the more appropriate to use.

The Pairwise Pearson correlation coefficient was calculated for the total number of respiratory patients and air pollution and the proportion of respiratory patients and air pollution. Pollution data included same day, 1-day lag, 2-day lag, 3-day lag and 4-day lag. Only particulate pollution 2-day lagged was consistently associated with both proportion of respiratory visits and total number of respiratory visits to the local GP surgeries. Table 2 shows the correlation between respiratory visits and air pollution. These correlations are significantly different from zero. Together with the plausible lag of two days between particulate pollution event and presentation at the surgery, they support the conclusion that the numbers of respiratory visits to the GP surgeries was directly related to the ambient level of $PM_{2.5}$ pollution.

Total respiratory visits were found to be significantly correlated with 2-day lagged air pollution levels. The proportion of respiratory visits was also correlated with 2-day lagged particulate air pollution.

The preliminary regression analysis, which included particulate air pollution, temperature, location of surgery and day of the week, indicated that the day of the week effects were not significant. A formal test

Table 3: Results of the estimated Poisson regression

Variables	Estimated Coefficient	Standard Error	p-Value
X	.0069	.0017	.0001
T	.0144	.0079	.0680
T_1	-.0028	.0109	.7934
T_2	.0076	.0091	.4033
T_3	.0012	.0081	.8790
T_4	.0234	.0080	.0036
C_1	.7603	.0826	.0000
C_2	.0188	.0980	.8475
C_3	.2577	.0823	.0017
C_4	-.1112	.1103	.3134
C_5	-.4957	.1232	.0001
Constant	1.1869	.0854	.0000

of the coefficients of the day of the week variables confirmed this. The final result, discussed below, shows significant associations between particulate air pollution ($PM_{2.5}$) and occurrence of respiratory symptoms requiring a GP's attention within the population in Armidale (with two-day lag).

Poisson regression results

Poisson regression results, giving estimates of the unknowns β_0 to φ_4, are shown in Table 3. The level of $PM_{2.5}$ pollution (X) is a significant influence (p<0.001) on number of respiratory cases presenting at GP surgeries.

In interpreting the results, two features should be noted. First, the coefficient in which we are mainly interested is β_1, associated with air pollution (x). Its value of 0.00693 means that an increase in $PM_{2.5}$ of 1µg/m^3, with all other factors unchanged, leads to a 0.693% increase in the number of respiratory patients. Alternatively, a one standard deviation (21.12 µg/m^3 of $PM_{2.5}$) increase in air pollution results in a 21.12 x 0.693 = 14.6% increase.

Second, suppose, for example, we are interested in the average number of respiratory patients attending surgery number 5 on a day in which air pollution is 24µg/m^3 of $PM_{2.5}$, and the minimum temperature is 2° Celsius and has been for the last 4 days. In this example, the variables in the model have the following values:

$X = 24$, $C_1 = C_2 = C_3 = C_4 = 0$, $C_5 = 1$, $T = T_1 = T_2 = T_3 = T_4 = 2$

Thus, by putting these values into the equation of Table 3, the resulting expected number of respiratory cases at surgery 5 is 2.574 patients.

n_r = exp[1.187 + (0.00693) (24 + (0.0145) (2 + (-0.0029) (2 + (0.0076) (2 + (0.0012) (2 + (0.0235) (2 + (-0.4957) (1]

= exp(0.9454)

i.e.: n_r = 2.574 patients

and so the average number of respiratory patients at surgery number 5 on all days with these characteristics is 2.57.

In exactly the same way, the model can be used to estimate the average number of respiratory patients for any combination of values of air pollution, surgery and minimum daily temperature.

To estimate the costs due to air pollution, we now use the model to disaggregate n_r into a part due to air pollution, with the remainder accounting for all other causes of respiratory illness.

First, we re-write equation 2 as:

$$X'\beta = a + b + c \qquad (2a)$$

where

$a = \beta_1 x$

$b = \beta_0 + \delta_1 C_1 + ... + \delta_5 C_5$,

$c = \varphi_0 T + \varphi_1 T_1 + ... + \varphi_4 T_4$.

Note that 'a' is determined by the value of air pollution alone, 'b' by the particular surgery and 'c' by the minimum temperatures.

Then,

$n_r = \exp(a + b + c) = \exp(a)* \exp(b)* \exp(c)$.

Also, because the absolute values of 'a' and 'c' are small relative to 1 for all values of the variables, we can approximate exp(a) and exp(c) by (1 + a) and (1 + c), respectively. Thus, n_r can be approximated by

$n_r = \exp(b)* (1 + a)* (1 + c) = \exp(b)* (a + 1 + c)$,

because (a * c) is always small enough to be ignored. Thus, finally,

$n_r = n_{r,x} + n_{r,o}$

where $n_{r,x}$ is that component of n_r attributable to air pollution alone, given by

$$n_{r,x} = a(\exp(b)) = \beta_1 x \exp(\beta_0 + \delta_1 C_1 + ... + \delta_5 C_5). \qquad (3)$$

To assist in the interpretation of (3), we define $n^{(i)}_{r,x}$ to be the contribution to $n_{r,x}$ due to the ith surgery.

Then

$$n^{(i)}_{r,x} = \beta_1 x \exp(\beta_0 + \delta_i) \qquad (4)$$

where i = 0,1,2,...,5

and $\delta_0 = 0$.

There are two factors that must be accounted for in order to estimate the number of pollution-caused respiratory patients in Armidale. The first is to obtain a better estimate of the number of patients at each surgery and the second is to aggregate to the city level. In most of the six surgeries surveyed, only some of the doctors completed the survey. We therefore apply 'expansion factors' α_i which adjust the values of $n^{(i)}_{r,x}$ to take this into account. For example, in surgery 2 only 2 of the 5 doctors actually completed the survey. We therefore adjust $n^{(i)}_{r,x}$ for this surgery by multiplying by α_2 = 5/2 = 2.5. Then to move to the aggregate city-level estimate a second factor γ = 26/22 =1.18 was applied to express the shift from the six represented surgeries with 22 GPs to the eight surgeries in the city with 26 GPs. Such an adjustment procedure is appropriate because the underlying regression model is linear (Hill et al. 2001). It makes the assumption that the case load of each GP is approximately the same.

Then, we define the estimated average number of pollution induced respiratory patients at surgery i, denoted by $N^{(i)}_{r,x}$, as

$$= N^{(i)}_{r,x} = \alpha_i n^{(i)}_{r,x} = \alpha_1 \beta_1 x \exp(\beta_0 + \delta_i) \quad (5)$$

The method for computing the number of pollution-caused respiratory patients per day for the whole of Armidale, for any given value of air-pollution (x), is simply to add the contributions for each surgery and apply the factor γ (=1.18). For example, for surgery 2 with adjustment factor α_2= 2.5, we obtain

$$N^{(2)}_{r,x} = 2.5\,\beta_1 x \exp(\beta_0 + \delta_2) = 2.5\,(0.006933)\ x \exp(1.187 + 0.01884)$$
$$= 2.5(0.023153)x = 0.05788x.$$

We note that the above expression is linear in x (the value of air pollution). It follows that over time, the average number of pollution-caused respiratory patients for this surgery can be obtained by replacing x by its average value, namely $\bar{x}$= 22.9. Thus, the daily average at surgery 2 = (0.05788)*(22.9) = 1.325 patients. This computation was carried out for each surgery, and the average daily number of respiratory patients (for the survey period) at the six surgeries which can be attributed to air-pollution is thus $N_{r,x}$= 7.45 persons. Then this is multiplied by γ = 1.18 to obtain 8.80 persons as the estimate for Armidale.

To estimate the proportion of these respiratory cases caused by $PM_{2.5}$ particulate air pollution we take the total number of respiratory cases reported by the GPs (=1370) and find the average per day, noting that there were 59 working days during the study period. This is 23.22. Thus the proportion related to $PM_{2.5}$ particulate air pollution is 37.9%.

Denoting the vector of estimated coefficients collectively by β, the standard error of $N_{r,x}$ is given by

$$\text{se}\,(N_{r,x}) = \gamma \bar{x}\ \frac{\partial N_{r,x}}{\partial \beta'}\ \text{cov}(\beta)\ \frac{\partial N_{r,x}}{\partial \beta} \qquad (6\ )$$

where cov(β) is the covariance matrix of β. Using the covariance matrix which accompanies the Poisson regression output, this expression can be evaluated to obtain

se ($N_{r,x}$) = 1.79

Economic cost

To assess the economic cost, only the cost of morbidity, as measured by the sum of doctors' fees, costs of medicine and wage losses, is considered. The cost of mortality was not included in this study because the sample size is too small to give a meaningful estimate. Moreover, if deaths had been recorded during the survey and included in the estimate of economic cost, it could have given a significant bias to the estimate. Elsewhere, Khan (2003) provides an estimate of this theoretical expected mortality cost in the study context as $6.4 million.

In our initial discussions with the New England Division of General Practice the figure of $35 was suggested as the average charge per visit. The GPs in the survey charged various fees from zero to $55. The mean was close to $40 per visit. Indexing this cost by changes in the CPI between December 1999 and March 2007 (Australian Bureau of Statistics [ABS] various dates) gives approximately $50.15 in 2007 terms. Doctors were asked to estimate their patients' costs for prescriptions and transport. The average prescription cost per patient was about $45 and, although more difficult to estimate, the average travel cost was about $5. Allowing for transport costs and medical prescription,a rough estimate of an additional $50 per consultation seemed reasonable. Indexing this cost by changes in the CPI gives approximately $62.70 in 2007 terms.

We assume that each visit takes one half day of an adult's time and that such time was valued at $61 based on the national annual wage rate for Australia (ABS 2000). Again indexing this by changes in the CPI gives about $76.50. While not everyone who seeks medical attention due to respiratory symptoms will miss half a day of work, the wage rate is considered a good reflection of the average value of time for this population. Some patients are children who do not earn wages, however, all visits for children include adult supervision, with a consequent potential wage loss.

Therefore, the total cost for each respiratory visit is estimated as

$50.15 + $62.70 +76.50 = $189.35

The average daily cost of pollution induced respiratory illness (for the survey period) is now obtained by multiplying the average number of respiratory patients by the cost of a respiratory visit. That is,

Average daily cost = $189.35 x 8.80 = $1,666.28.

The standard error of this cost estimate is $189.35 x 1.79 = $338.94.

Discussion and Limitations of Findings

The result of both the correlation and regression analysis shows that there was an association between respiratory-related GP visits and particulate air pollution in Armidale.

Major findings

There are three main findings from the study.

i. During the survey period, the average number of respiratory patients due to particulate air pollution in Armidale was 8.80 persons/day.

ii. Approximately 38% of the total respiratory visits to local GP clinics were due to particulate air pollution.

iii. Taking into consideration the costs and expenses arising from such ailments, the average daily economic cost of respiratory symptoms due to particulate air pollution was estimated to be $1666.

The estimated economic cost is conservative, and it only considers the direct medical costs. Dollar outlays were calculated in terms of GPs' usual charge for surgery visits, cost of drugs, and time loss estimated on the basis of the average wage rate. Related costs, such as X-rays, hospital admission, emergency room visits, alternative medicines and so on, and costs associated with 'pain and suffering', and mortality have been ignored.

Conceptually, the monetary aspect could be extended further. One important step would be to estimate the value of missed schooling and work loss. Contingent valuation techniques (Karimzadegan et al. 2007) might yield estimates of willingness to pay by the people of Armidale for the value of 'pain and suffering' due to respiratory symptoms.

The study did not take account of preventive or defensive measures, which could contribute to an underestimation of economic cost. For example, asthma can be controlled with maintenance treatment. Many asthma patients experience mild symptoms and treat themselves with medication instead of reporting to a GP. Such cases are not captured in the GP reports. Asthma also affects people chronically, and the estimate only captures exacerbation due to fluctuations in pollution levels.

As the clinical survey was based on respiratory visits to local GPs, the study excluded hospital admission and emergency room visits. Patients with severe asthma attacks, who normally go to the hospital emergency department rather than to surgeries, have not been included. In many cases, asthma imposes significant costs on persons with symptoms and their families. Researchers have used the cost-of-illness method to estimate the direct and indirect costs of asthma prevalence for several developed economies, including the US, Canada and the United Kingdom (UK). Barnes et al. (1996) tabulated summary measures from nine studies in which direct costs typically contributed 50 to 60% of total costs.

In one of the earlier studies assessing the economic costs of air pollution, Ransom and Pope (1992), compared hospital admissions and mortality data before and after the temporary closure of a steel mill in a mountain valley in central Utah. They estimated that the annual increase in hospitalisation costs was US$2 million and more than US$40 million in mortality costs, due to particulate emissions.

Zaim (1997) estimated that by reducing its air pollution to WHO levels from 1993, Turkey would have reduced annual hospital admissions for respiratory diseases by 5480, annual emergency room visits by 112,100, avoided 6.85 million restricted activity days per year and 73,000 cases per year of low respiratory symptoms in children 0-12 years of age. The estimated annual economic value of avoiding these effects represented nearly 0.08% of Turkey's 1993 gross national product.

It is clear from the above that inclusion of emergency room visits, hospital admissions and mortality would substantially increase the estimate of the economic cost of particulate air pollution in Armidale.

Conclusion

Implications of findings

The findings from this study have several implications. One is that an improvement in air quality from a reduction in woodsmoke particulate pollution in Armidale can lead to both health and economic benefits to society. The economic cost estimated in this study was limited by the available data and should be regarded only as providing a *lower bound*. If additional data on hospital admissions, emergency room visits, willingness to pay, and so on were available, a more realistic assessment of economic costs could be obtained. In terms of public health, there is a clear case to consider policies that encourage the replacement of wood burning as a source of domestic heating. Indeed, supported by the EPA, the Armidale Dumaresq City Council has adopted a policy of providing incentives to householders for the removal of wood heaters.

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Estimating Optimum Population for Sustainable Development: A Case Study of South Korea

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Overpopulation has been argued as a main cause of environmental problems in terms of sustainable development. Nonetheless, it is rare to undertake theoretical and/or empirical research on optimum population in relation to sustainable development. The aim of this paper is, therefore, to estimate an optimum population for sustainable development in South Korea. To fulfil this aim, two methods were developed, using multiple regression analysis of ten-year time series data (from 1993 to 2002). The first method concerned the objective states of environmental components. The second was drawn from questionnaire survey data that measured public consensus on the desirable states of these environmental components. A different number for optimum population was estimated by the former according to the scenarios, but 50.46 millions by the latter. This means that the optimum population for sustainable development is not a fixed number. Rather, it is dependent upon the values of the variables included in the estimation. The findings showed that, of the variables used, environmental budget and clean energy supply are the most crucial in determining the optimum population for sustainable development of South Korea. However, different optimum population levels are estimated according to environmental variables.

Key words: *Environmental Problems; Impact of Population on Environment; Environmental Impact; Appropriated Carrying Capacity; Sustainable Development; Optimum Population*

A diverse number of factors have been suggested as the causes of the current environmental problems. They include population growth (Ehrlich 1968), the West's anthropocentric values and orientations drawn from Judaic-Christianity (McHarg 1992; Toynbee 1972; White 1967; Yoo 1996), the socio-economic forces encouraging both population growth and technological innovation (Schnaiberg 1980), economic development and inequality (Schumacher 1973; Van den Bergh & Van der Straaten 1994), competitive functions of the environment (Catton & Dunlap 1989), and social class issues in which the corporation and the state line up in opposition to ordinary citizens (Cable & Cable 1995). Environmental economists also maintain that market failure of environmental resources is a significant cause of environmental problems (Jeong 1997).

The causes of environmental problems relate to the process and/or outcomes of industrialisation that have advanced since the eighteenth century in Western Europe and that have since spread throughout the world. In this sense, industrialisation is considered the primary cause of current environmental problems (Foster 1994; Kassiola 1990; Orr 1979).

This paper explores the implication of population growth as a cause of environmental problems. In particular, it seeks to estimate optimum population in terms of sustainable development. Much research on optimum population has been done in terms of the economic perspective since Malthus' essay on population in the eighteenth century (Dasgupta 1969). Some economists balance population against their environmental impact, coming up with their own value judgment. In terms of the concept and implication of sustainable development, the economists' perspective is optimistic, because overpopulation has been argued as a cause of current environmental problems since the 1960s (Borgstrom 1969; Ehrlich 1968). Nonetheless, theoretical and/or empirical research on the population size that is optimal for sustainable development either at the level of a country or of the world has rarely been conducted.

While being much like a research puzzle, this paper aims at estimating the optimum population of South Korea as a case study in terms of sustainable development. To do this, we have developed two methods, one focusing upon the objective states of environmental components, and the other upon the public consensus on the desirable environmental components.

To fulfil this aim, the paper is divided into four parts. First, we review the concept of 'environment' in order to understand the relationship between the environment and populations. Second, the impact of the population on the environment is reviewed. Third, a model for estimating optimum population is developed in relation to sustainable development. Finally, the optimum population is estimated on the basis of the model.

The Concept of Environment

The initial definition of the environment can be traced back to the 1950s when human ecology was the main type of sociological research on the link between humans and the environment. For example, Hawley (1950, pp. 12-13) defined the environment as all external forces and factors to which an organism or aggregate of organisms is actually or potentially responsive. Based on this definition, human ecologists including Hawley (1950) classified the environment into two categories: natural and social. The former refers to the components of nature, and the latter relates to human-made elements such as land price, technology, transportation, culture, and social institutions.

In the early 1960s, Duncan (1961) introduced sociology to the notion of environment, the so-called POET (Population, Organisation, Environment and Technology) approach, which was depicted as an ecological complex. According to POET, an increase in population (P) can create pressure for technological change (T) as well as excessive urbanisation (O), resulting in much greater pollution (E).

In the 1970s, on one hand, Dunlap and Catton (1979) classified the environment into natural (e.g. air, soil, water, climate), social (e.g. social relations such as competition, cooperation, symbiosis, and functional interdependence), modified (e.g. polluted and/or destroyed natural environment), and built or human-made (e.g. houses, towns, roads). On the other hand, Martell (1994, pp. 169-170) developed a model termed 'the ecological complex: an extended version' using the components of the POET model as well as Dunlap and Catton's (1979) environment categories. Martell (1994) focused on the explanation of three matters: the causes and effects of social development, the causes of current environmental problems, and environmental effects on society.

In sum, the environment is defined as the external factors surrounding humans. The external factors include aspects such as the natural, modified, social, built, and human-made. However, they can be conceptualised as two key elements: natural and human-made. The modified environment connotes the nature that is polluted and/or destroyed. The social and built environments are created by humans for the benefit of material and cultural affluence, convenience of life, and efficiency in running society. Thus, the two non-natural constituents can be synthesised into one term, the human-made environment. In particular, the human-made environment can be classified into two categories in terms of whether they are visual or not. The visual ones, such as factories, can be termed as a human-made physical environment, whereas the non-visual characteristics such as culture and values can be described as a human-made non-physical environment.

Therefore, it can be maintained that the environment as an entity surrounding humans, consists of at least three categories: the natural, the human-made non-physical, and the human-made physical. The relationships among the three components of environment and humans are in a mutual causal relationship in terms of determining their mode of existence.

The Impact of Population on the Environment

The impact of population on the natural environment can be approached in two ways (Jeong & Chang 2005). One is to focus on individual behaviour towards the natural environment that is performed in everyday life and the other is to evaluate the total number of people. The former can be termed 'population as an actor', and the latter 'population as an aggregate'. The notion that population growth is a cause of environmental problems emphasises population as an aggregate.

The original integrity of nature is often destroyed and/or polluted in the process of resource extraction. When liquid, aerial, and solid wastes are discharged during the process of producing capital and/or consumption goods; these wastes return to nature. Nature is often polluted and destroyed in the process of distributing goods and services. Humans directly pollute and destroy nature during everyday activities. Therefore, it can be argued that the bigger the population size, the greater the volume of resources extracted and wastes discharged.

It is in such a context, that empirical research on the impact of the population as an aggregate on the natural environment has been conducted since the early 1990s. Two techniques for the empirical research have been developed. One is to estimate the environmental impact, and the other is to estimate appropriated carrying capacity.

Environmental impact is defined as the impact of a population as an aggregate upon its natural environment and ecosystem (Harper 2004; Sage 1995). Environmental impact data provide valuable information regarding the impact of the human use of natural resources. Empirical research, using South Korea as a case study, identified the fact that adverse environmental impacts had increased by 1.115 times over 10 years from 1993 to 2002 (Jeong & Chang 2005).

Appropriated carrying capacity (hereafter ACC) is defined as the aggregate land area with both the capacity to continuously provide the required resources presently consumed, and to continuously absorb all associated wastes (Wackernagel et al. 1993, p. 10). What this means is that it is not about 'How many people can the earth support?' but rather 'How much land do people need to support themselves?'. ACC is assessed by dividing the size of the ecological footprint (hereafter EF) into the area of suitable land which is available.

Some empirical research on ACC estimates has been done. Examples include work by Wackernagel et al. (1993) on Canada, Bicknell et al. (1998) and McDonald and Patterson (2003) on New Zealand, and Chambers, Simmons, and Wackernagel (2000) on 52 countries as a comparative study. The World Resources Institute (1992), Chambers et al. (2000), and The World Wildlife Fund (2002) have estimated the ACC for the entire world as a unit.

Typically with such empirical research, critical debate arises as to its conceptual basis (e.g. Ayres 2000; Moffatt 2000) and the validity of the calculating method and the subsequent results (e.g. Danish Environmental Assessment Institute 2002; van Kooten & Bulte 2000; Vegara 2000). Meanwhile, some scholars (e.g. Van Vuuren & Smeets

2000) argue that despite the debates, it is successful in providing an interesting basis for discussion about the environmental effects of consumption patterns of population, including those outside the national borders, and the social inequality in regard to resource access. Even recently, the strengths and weakness of ACC as an ecological accounting method are still discussed (Wackernagel & Yount 2000). In accordance with this, Wackernagel et al. (2004) have tried to resolve the conceptual challenges of EF.

According to the work on ACC for the entire world as a unit (e.g. Chambers et al. 2000; World Resources Institute 1992; World Wildlife Fund 2002), the earth exceeds the ACC by 2.50 times. South Korea exceeded ACC by 9.250 times in 1995 (Chambers et al. 2000, p. 122). In detail, the average EF per capita was 3.7 ha, available biocapacity per capita 0.4 ha, and ecological deficit per capita 3.2 ha. Recent empirical research on South Korea shows that the EF has increased since 1995 (Wackernagel et al. 2004), and is larger than China (Chen et al. 2006).

Recently, EF is extended in terms of its concept and methodology. In terms of the extended and/or refined concept, the concept of human appropriation of net primary production (hereafter HANPP) was suggested. The HANPP maps the intensity of societal use of ecosystems in a spatially explicit manner (Haberi et al. 2004; Wackernagel et al. 2004). In addition, the concept of EF is distinguished between a consumptive and a productive one, between an internal and an external one, between the total ecological carrying capacity and the capacity that is available (Dai et al. 2006). The concept of embodied exergy ecological footprint (hereafter EEF) as a modified one was suggested in 2007. The EEF serves as a modified indicator of ecological footprint and goes toward illustrating the productions of resources, environment, and population and thereby reflecting the ecological overshoot of the general ecological system (Chen & Chen 2007).

In terms of the methodology of EF, the original calculation of EF was based on humans-resources supply, waste absorption, and space occupied for human infrastructure. However, other items such as CO_2 emission (Roberts et al. 2003) and energy use in general (Du 2006) are included in the calculation of EF. In sum, there is no doubt that EF is a method for measuring sustainable development through ecological impact, but like most methodologies in social science, the EF method still has limitations and weakness (Du et al. 2006).

The Method to Estimate Optimum Population for Sustainable Development

The first step to estimate optimum population for sustainable development is to define the concept of optimum population. The second step is to select the appropriate variables as the determinants of optimum population in relation to sustainable development. Finally, a valid analytic technique for estimating optimum population should be employed.

Optimum population

The discussion of overpopulation and optimum population was initiated in the discipline of economics. A key figure in this area was Malthus (Dasgupta 1969) whose theory was based on a two-variable dynamic model of the interrelated effects of income and population. In economics, overpopulation is not merely a numerical demographic fact describing 'too many people', rather it is about production arising from the manner in which land and other resources are used (McNicoll 2005). By contrast, optimum population is defined as the population that achieves a given aim in the most satisfactory way (for different approaches to the definition, see Dasgupta 1969). This definition implies that optimum population will be different according to the aim that one seeks to achieve in considering 'the most satisfactory way', which in this paper, is viewed as sustainable development.

Selection of variables

When the focus is on sustainable development, variables to be considered as the determinants of optimum population include environment, economy, and society, all of which are the major conceptual components of sustainable development. As an example, an Australian Senate Committee, the Senate Standing Committee Australia or SSCA (1994), has estimated the optimum population in Australia in terms of carrying capacity using the main empirical concept of sustainable development, including technology options, possible patterns of resource use and quality of life. Pimentel et al. (1994) argue that the earth's long-term sustainability calls for a population of less than half its present level, in particular, with a focus on resources as a sub-category of the natural environment. Lutz et al. (2002) developed the PEDA (Population-Environment-Development-Agriculture) model on the basis of the interactions between population growth, education, land degradation, agricultural production, and food insecurity. McNicoll (2005, pp. 4-5), on the other hand, argues that the built environment and subjective welfare of the average inhabitants should be included in estimations of the optimum population.

The research cited above found that the determinants of optimum population in relation to sustainable development should include the components of the natural environment and those of the human-made environment as explained in the previous section. In this context, this paper classifies the determinants of optimum population into five categories on the basis of the components of the natural and the human-made environment - amenity, convenience, affluence, efficiency, and safety (Jeong 2002, p. 36). Each of them is composed of sub-dimensions which can be measured empirically by individual indicators, as is shown in Table 1. The five categories can be defined as below if they are referred to within the category of the environment as a determinant of sustainable development.

Amenity: Amenity is a physical aspect related to a comfortable environment such as the living conditions, density of population and the seriousness of environmental degradation. Environmental policy can also be included as a sub-dimension of amenity due to its aim of improving the quality of the natural environment. In this sense, amenity is determined by both the natural and the human-made environments.

Convenience: Convenience refers to the ways to save time or physical or mental resources, covering at least two sub-dimensions: how efficiently people and materials move spatially and temporally; and how conveniently people live in everyday life. Thus, convenience is determined by the human-made environment only.

Affluence: Affluence is a situation in which people live above a determined threshold. This threshold depends upon value judgments

Table 1: The categories of the determinants of optimum population for sustainable development

Categories	Sub-Dimensions
Amenity	Density, Living Conditions, The State of Nature Polluted and/or Destructed, Policy for Preserving the Natural Environment
Convenience	Spatial Mobility, Everyday Life
Affluence	Material Affluence, Cultural Affluence, Social Affluence
Efficiency	Improvement for Individual People, Improvement for Society as a Whole
Safety	Health and Sanitation, Social Problems

and is relative in terms of material, cultural, and social dimensions, and thus is determined by the human-made environment only.

Efficiency: Efficiency means to take the shortest path and the cheapest means to attain desired goals. Human-made environments are established in order to improve efficiency for the quality of people's lives and society in general. This is why efficiency can comprise improvement for both individuals and society.

Safety: Human life ought to be safe. Safety can be regarded as physical health without disease, and a society without social anxiety in relation to crimes and accidents.

Analytical techniques: Each society has a limited capacity which is determined by the availability of the natural and human-made resources. This limitation can be termed social capacity (Jeong 2002, pp. 226-234). In this sense, applying social capacity to population reveals the optimum population determined by the components of the natural and human-made environment within a society. Thus, population size is the dependent variable, and the components of the natural and human-made environment are the independent variables. The population levels estimated from this calculation represent the optimum population a society can enjoy for sustainable development.

Regression analysis can be used to estimate the operational concept of optimum population in terms of sustainable development, using population as the dependent variable, and the state of the natural and human-made environment as the independent variable.

Results

Estimated optimum population of South Korea

As mentioned above, this study used population as the dependent variable, and the states of the natural and human-made environment as the independent variables. The independent variables were selected on the basis of the following guides and procedures.

A ten-year time series data set (from 1993 to 2002), including population, which was available from the statistical yearbooks published by the South Korean government, was collected. The impact of each variable on the determination of optimum population size for sustainable development will be different. The difference can be defined as the 'relative importance of each variable'. The relative importance should be considered when we estimate the optimum population size. The statistical techniques, such as regression analysis and factor analysis, which derive the relative importance of a variable, require a set of time-series data.

Fifty-five variables including population were available from the statistical yearbooks. The variables whose correlation coefficients with population higher than 0.900 at a significant level of 0.001 were identified. Nine were selected as the final independent variables determining population in the order of a high correlation coefficient. They were the quantity of sewage discharged, the area of landfill of wastes, the percentage of environmental budget compared to the total government budget, the density of sulfurous acid gas, the supply of clean energy, the capacity of sewage treatment, the reuse rate of wastes, the gross domestic product (GDP) per capita, and the number of physicians. Table 2 shows the ten-year time series data for the nine independent variables and population.

The reasons for selecting nine variables were as follows. The study used a ten-year time series data set which corresponded to a sample size of 10. The number of the independent variables in regression analysis should be less than the sample size.

Regression equation set up to estimate the optimum population

A multiple linear regression analysis, which enables us to estimate B coefficient as the relative importance of each variable, were applied for estimating optimum population

Table 2: The final variables and their data for estimating optimum population

Years	Population[1]	Amenity: Discharged Sewage[2] (kg/day person)	Amenity: Landfill of Wastes[2] (km2)	Amenity: Environmental Budget[2] (% of Total Budget)	Amenity: Sulfurous Acid Gas[2] (ppm)
1993	44,194,628	1.424	37,190	0.37	0.022
1994	44,641,540	1.302	35,114	0.73	0.023
1995	45,092,991	1.059	34,678	0.90	0.018
1996	45,524,681	1.097	34,468	1.04	0.014
1997	45,953,580	1.042	34,918	1.10	0.013
1998	46,286,503	0.963	36,382	1.01	0.010
1999	46,616,677	0.978	35,923	0.96	0.010
2000	47,008,111	0.988	35,923	1.04	0.009
2001	47,342,828	1.024	38,376	1.01	0.007
2002	47,639,618	1.047	39,139	0.98	0.006

Data Sources:
1) Korea National Statistical Office, South Korea. Korea Statistical Yearbook.
2) Ministry of Environment, South Korea. Environment Statistical Yearbook.
3) Ministry of Industry and Resources, South Korea. Statistical Yearbook.
4) The Bank of Korea, South Korea.
5) Korea National Statistical Office, South Korea. Korea Statistical Yearbook.

Years	Amenity: Supply of Clean Energy[3] (10,000 TOE/year)	Amenity: Capacity of Sewage Treatment[2] (1,000 tons/day)	Amenity: Reuse Rate of Wastes[2] (%)	Affluence: GDP per Capita[4] (US$)	Safety: Number of Physicians[5] (physicians/10,000 population)
1993	102.5	7,911	39.1	7,811	38.5
1994	97.3	9,389	38.4	8,998	41.3
1995	102.3	9,653	42.6	11,432	43.8
1996	103.4	11,452	46.3	12,197	45.6
1997	136.5	15,038	46.7	11,176	47.6
1998	135.7	16,616	50.8	7,355	48.6
1999	136.7	17,712	55.9	9,438	51.6
2000	149.7	18,400	57.9	10,841	52.2
2001	145.2	19,230	59.5	10,162	56.1
2002	184.7	20,245	60.2	11,493	60.5

size. The regression equation was set up as Formula 1.

As the above regression equation suggests, the nine variables explain 71.4% as the determinants of optimum population in South Korea. This means that 28.6% of optimum population is determined by other factors than the nine variables. The following facts can be proposed from Formula 1.

As GDP per Capita and Wastes Discharged increase, the optimum population decreases. For the other seven variables, as their values increase, so does the optimum population. The reasons for these can be interpreted as follows.

Formula 1: Regression equation for estimating optimum population in South Korea

$$Y = -9{,}048.685X_1 + 149.139X_2 + 3.070X_3 + 105{,}035.885X_4 + 6{,}420.584X_5 + 60{,}814{,}586.000X_6 + 2{,}263{,}161.200X_7 + 17.9000X_8 + 246.466X_9 + 31{,}788{,}258$$

$(R=0.845,\ R^2=0.714)$

Y: Optimum Population
X_1: Discharged Sewage (kg/day(person)
X_2: Landfill of Wastes (km2)
X_3: Capacity of Sewage Treatment (1,000 tons/day)
X_4: Reuse Rate of Wastes (%: wastes reused/total wastes discharged)
X_5: Supply of Clean Energy (1,000 TOE/year)
X_6: Sulfurous Acid Gas (ppm)
X_7: Environmental Budget (%: environmental budget/total budget)
X_8: GDP per Capita (USD)
X_9: Number of Physicians (Physicians/10,000 population)

Wastes Discharged is a key factor in exceeding the carrying capacity of nature through pollution and/or degradation. The increase in GDP per Capita is based on the increase in the production of goods and services that are the sources of diverse types of pollution. Therefore, an increase in GDP per Capita is in conflict with the preservation of nature. This conflict is the main reason behind the emergence of the idea of sustainable development. The reason why the five variables - Landfill of Wastes, Capacity of Sewage Treatment, Reuse Rate of Wastes, Supply of Clean Energy and Environmental Budget - are positive on the increase in the optimum population is that they are all important factors to decrease or prevent the pollution and/or destruction of nature. The Number of Physicians is also a positive factor for the increase in the optimum population. This is because the physicians contribute to the increase in the quality of life in terms of human health.

Theoretically, it is clear that the greater density of Sulfurous Acid Gases should correspond with a lower optimum population. Nevertheless, Formula 1 identifies that Sulfurous Acid Gas has a positive impact on the increase in the optimum population. This suggests that the higher the legal allowance of discharging Sulfurous Acid Gas, the bigger the optimum population.

However, the impacts of the nine variables on optimum population are different. For example, if Waste Discharged is lessened by 1kg, the number of optimum population increases by 9049. If the Reuse Rate of Wastes increases by 1%, if 100 thousand TOE of clean energy is supplied a year, and if the Environmental Budget increases by 1%, the number of optimum population increases by 105,036, 642,058, and 2,263,161, respectively.

The increase in GDP per Capita by US $1000 decreases the optimum population by around twice the increase in Sewage Discharged by 1kg a day per person. The density of Sulfurous Acid Gas is 0.006ppm as of 2002. If the regulation of its density increases to 0.010ppm, the optimum population will correspondingly increase by 608,145.

As such, an increase in the Environmental Budget has the strongest impact on the increase in the optimum population, followed by an increase in Clean Energy Supplied, Sulfurous Acid Gas and an increase in the Reuse Rate of Wastes. Even though the increase in the Capacity of Sewage Treatment and the Number of Physicians increase the optimum population, their impacts are relatively lower than when compared to the other variables.

Table 3: optimum population estimated by scenarios when GDP per capita is US$20,000 and the sulfurous acid gas is regulated at 0.006ppm

Scenario 1
- The states of the remaining seven independent variables are as in 2002
- Optimum population: 47,487,325

Scenario 2
- Discharged Sewage, Landfill of Wastes, Supply of Clean Energy, Capacity of
- Sewage Treatment, Reuse Rate of Wastes, and Number of Physicians are the same as of 2002
- Environmental Budget increase to 2.00% from 0.98% in 2002
- Optimum population: 49,795,749

Scenario 3
- Environmental Budget is 0.98% as in 2002
- Discharged Sewage per person per day reduces to 0.500kg from 1.047kg as in 2002
- Landfill of Wastes extends to 50,000km2 from 39,139km2 as in 2002
- Supply of Clean Energy increases to 250.0 thousand TOE a year from 184.7 thousand TOE as in 2002
- Capacity of Sewage Treatment a day increases to 30,000 thousand tones from 20,246 thousand tons as in 2002
- Reuse Rate of Wastes increases to 65.0% from 60.2% as in 2002
- Number of Physicians per 10,000 population increase to 70.0 from 60.5 as in 2002
- Optimum population: 50,077,302

Scenario 4
- Discharged Sewage per person per day reduces to 0.500kg from 1.047kg as in 2002
- Landfill of Wastes extends to 50,000km2 from 39,139km2 as in 2002
- Supply of Clean Energy increases to 250 thousand TOE a year from 184.7 thousand TOE as in 2002
- Capacity of Sewage Treatment per day increases to 30,000 thousand tones from 20,246 thousand tons as in 2002
- Reuse Rate of Wastes increases to 65.0% from 60.2% as in 2002
- Environmental Budget increases to 2.00% from 0.98% as in 2002
- Number of Physicians per 10,000 population increases to 70.0 from 60.5 as in 2002
- Optimum population: 52,385,726

Optimum population estimated by scenarios

Using Formula 1, the optimum population can be estimated on the basis of the objective states of the nine independent variables. This suggests that the optimum population is estimated differently according to the objective states of the nine independent variables. Therefore, the number of the optimum population is not fixed, rather it varies according to values of the nine independent variables. We call this ‘optimum population by scenarios’, as it involves the application of the different values of the nine independent variables.

The South Korean government seeks to achieve a GDP per Capita of US $20,000 by 2010 (MOE 2003), and regulate the density of Sulfurous Acid Gas as 0.006ppm from 2007 (MOE 2003). Table 3 shows the optimum population estimated in South Korea by four scenarios on the basis of US $20,000 and 0.006ppm.

As of 2006, total number of population in South Korea is 48,460,000. The optimum population can vary according to the goal of government policy for each of the independent variable (see Table 3). For example, the optimum population is estimated as 47,487,325 for Scenario 1; 49,795,749 for Scenario 2; 50,077,302 for Scenario 3; and 52,385,726 for Scenario 4. Different numbers for optimum population can also be calculated if other scenarios than those in Table 3 are applied.

Table 4: South Koreans' values on the conditions of the nine independent variables to be desirable

Independent Variables	Measurement Unit	Rates in 2002	Desirable Future Rates	Increase/Decrease since 2002
Discharged Sewages	kg/day per person	1.047kg	0.942kg	▼ 10.02%
Landfill of Wastes	km2	39,139km2	37,852km2	▼ 3.29%
Capacity of Sewage Treatment	1,000 tons/day	20,245 thousand tons	20,743 thousand tons	▲ 2.46%
Reuse Rate of Wastes	% of total wastes	60.2%	67.4%	▲ 12.03%
Supply of Clean Energy	1,000 TOE/year	184.7 thousand TOE	207.9 thousand TOE	▲ 12.54%
Sulfurous Acid Gas	ppm	0.006ppm	0.005ppm	▼ 10.01%
Environmental Budget	% of total budget	0.98%	1.08%	▲ 10.58%
GDP per Capita	US$	US$11,493	US$12,874	▲ 12.01%
Number of Physicians	per 10,000 population	60.5	66.2	▲ 9.44%

Note: ▲ Increase ▼ Decrease

Optimum population based on social consensus

People might hold different levels of expectation regarding the desirable levels of environmental robustness. In this context, social consensus is defined as the values that people hold in relation to the environment and what constitutes an acceptable level of pollution.

A sample survey with 1100 respondents of 20 years of age and over was conducted in South Korea in order to identify the desirable level of each of the nine independent variables. The survey was nationally conducted through the Internet. Questionnaires were sent to randomly selected respondents and responses were received by email. The respondents were asked to describe the desirable level of the nine independent variables. The mean values of the responses on each independent variable were calculated (see Table 4).

It is worthwhile pointing out the following five points from Table 4. First, the public expressed the view that the current levels of Sewage Discharged, Landfill of Wastes, and Sulfurous Acid Gas, should decrease. The desirable decrease rate is highest for Sewage Discharged, followed by Sulfurous Acid Gas and Landfill of Wastes.

Second, the public expressed the view that the Capacity of Sewage Treatment, Reuse Rate of Wastes, Clean Energy Supplied, Environmental Budget, GDP per Capita, and Number of Physicians, should increase beyond their current levels. The desirable increase rate is highest for Supply of Clean Energy, followed by Reuse Rate of Wastes, GDP per Capita, Environmental Budget, Number of Physicians, and Capacity of Sewage Treatment.

Third, the variables which the public perceive to decrease relatively higher are Sewage Discharged and Sulfurous Acid Gas. On the contrary, variables whose increase rate is relatively higher are Reuse Rate of Wastes, Clean Energy Supplied and Environmental Budget. This suggests that the public want the factors related to the sources of current environmental problems to decrease, and the factors related to the prevention of environmental degradation to increase.

However, the public's consciousness is higher on the latter than on the former in terms of the increase and/or the decrease rate.

Fourth, interestingly, even though GDP per Capita is a factor that can increase environmental problems, people also want the GDP per Capita to increase. This might be caused by two factors: people might not be aware that the increase in GDP could have a negative impact on the environment, or that people want to enjoy more material affluence even though they know that the increase in GDP might have a negative impact on the environment.

Finally, based on the social consensus of the value of each variable specified in Table 4, the optimum population of South Korea for sustainable development is estimated at 48,503,241 when Formula 1 is used.

The South Korean government currently pursues the goal of GDP per Capita of US $20,000, and aims to increase the Environmental Budget to 2.00%. When examining this scenario using Formula 1, these two values and the desirable states of the remaining seven variables that were pin-pointed by the public (see Table 4), estimate the optimum population as 50, 457, 794.

Conclusion

Overpopulation has been cited as a cause of environmental problems. However, no theoretical and/or empirical research has been carried out on the optimum population in relation to sustainable development in a particular country or in the world as a whole. This paper, as a case study, aimed to estimate the optimum population of South Korea in terms of sustainable development. For this objective, a 10-year series data (from 1993 to 2002) for 55 environmental variables including population were collected. The variables whose correlation coefficients with population are higher than 0.900 at a significant level of 0.001 were identified. Nine were selected as the final independent variables determining population in the order of a high correlation coefficient. They were the quantity of Sewage Discharged, the area of Landfill of Wastes, the percentage of the Environmental Budget to the total government budget, density of sulfurous Acid Gas, supply of Clean Energy, Capacity of Sewage Treatment, Reuse Rate of Wastes, Gross Domestic Product (GDP) per capita, and number of physicians. They cover a wide range of factors such as those related to the current environmental state. The reasons for selecting nine independent variables were that this used 10-year time series data which corresponded to a sample size of 10, and the number of the independent variables in regression analysis should be less than the sample size.

A multiple regression analysis was used to estimate the optimum population, using population as the dependent variable and nine environmental variables as independent variables. The results and implications can be concluded as below.

The population of South Korea as of 2004 was 48 million. However, the minimum optimum population estimated for sustainable development was approximately 47.5 million when considering the desired rates of the nine environmental variables that were evaluated in this paper.

Among the nine independent variables, seven variables were drawn from the category of amenity, one variable from affluence, and one variable from safety. However, no variable was drawn from the category of convenience. Therefore, it can be argued that the natural environment impacts much more strongly on the determination of optimum population than the human-made environment. Among the variables that represent amenity, government policies (Environmental Budget and Clean Energy Supplied), which function to prevent environmental problems are stronger determinants of optimum population than Landfill of Wastes and Capacity of Sewage Treatment, which function to deal with current environmental problems.

This fact implies that the environmental policy applied to nature prior to the onset of environmental problems is more effective in increasing optimum population than activities applied to solve the environmental problems *ex post facto*.

Overall, optimum population is maximised when Sewage Discharged is minimised and the values of the other eight independent variables are maximised. Interestingly, even though GDP per Capita is a factor in decreasing optimum population, its impact is not great. There are two reasons that might explain this fact. First, the increase in GDP per Capita in South Korea depends greatly on imported materials. This fact implies that the increase in GDP per Capita is not proportional to the pollution and/or destruction of nature. Second, advanced technologies and the high reuse rate of wastes functions to decrease processing pollution, which occurs when producing capital and consumption goods.

As the legal regulation of Sulfurous Acid Gas loosens, optimum population increases, whereas the amenity correspondingly decreases. This fact might imply that the social consensus on the acceptable level of air pollution in everyday life is a significant determinant of optimum population. In this context, the optimum population varies according to the public's values concerning acceptable pollution level.

A major characteristic of the public's values is that the sources giving rise to environmental problems should decrease, and the factors related to the prevention of environmental problems should increase. However, their values are higher on the latter than on the former. This would mean that the public emphasises *a priori* factors to be more important than *ex post facto* factors.

Based on the social consensus identified from the sample survey, the optimum population estimated was 48,503,241. If government policies were considered as a way to increase the Environmental Budget and GDP per Capita, the optimum population is estimated at 50,457,794.

In conclusion, the 10-year time series data used in this research represents the experience of South Korea over that time. Therefore, if the experience is different, the regression equation is likely to differ, which would lead to different estimations of the optimum population. To determine an optimum population, assumptions would have to take into account a long list of parameters, such as the standard of living, the desire for development and environmental quality, all of which are by no means static. The results cited here are based on a limited number of parameters, however, a complex measurement instrument has been partially developed. Further development of this model would prove useful for policy formation and management for sustainable development.

Given that people wish to retain natural values and a good quality of life, it seems clear that there has been an overshoot of population size related to the appropriated carrying capacity. The issue is whether this overshoot will be followed by a stabilising oscillation between appropriated carrying capacity and population size or a crash of both. The former would enable an optimum population to occur if environmental impacts could be greatly reduced. The second overshoot model means a large-scale ecological collapse characterised by the loss of both ecological biodiversity and function, and a consequent drastic fall in the human population.

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Legionella and Protozoa in Cooling Towers: Implications for Public Health and Chemical Control

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In recent years, technical and regulatory controls on the operation and maintenance of cooling towers within Australia have increased. Chemical treatments for microbial control have primarily focused on effects against bacteria and in some instances, specifically on Legionella. *There is strong evidence to suggest that the presence of protozoa contributes significantly to the survival of* Legionella *in cooling towers and might be an important consideration for health risk management strategies.*

Key words: *Amoebae; Biocides; Cooling Towers;* Legionella*; Protozoa*

The presence of *Legionella* in cooling towers has long been associated with outbreaks of disease. This was recently demonstrated by the Melbourne Aquarium outbreak in 2000 where 125 cases of Legionnaires' disease and four deaths were reported (Greig et al. 2004). Protozoa are likely to contribute to the survival of *Legionella* in cooling towers and their control has been proposed as a major method for minimising *Legionella* proliferation (Fields et al. 2002). However, the microbial ecology of cooling towers is complex, and requirements for effective protozoan control strategies are not fully understood.

Cooling Tower Operation

Cooling towers are designed to cool water and dissipate heat to the environment and are often associated with air conditioning, refrigeration systems and other large plant. In typical operation, warm water from a heat exchanger is sprayed into the top of a large chamber over packing material known as fill. The water droplets partially evaporate and lose heat to the surrounding air by conduction and convection as they fall through the tower. The water collects in the basin where it can be recirculated to the heat load. Typical water temperatures in cooling towers range from 25°C in cool areas to up to 35°C at heat exchange surfaces. The constant fall of water through the fill creates aerosol, of which, a proportion is lost from the cooling tower through 'drift'. Drift will contain any bacteria, and any organic and inorganic material present in the water. The transmission of aerosol over distances of up to 12km from cooling devices has been reported (Nguyen et al. 2006). The loss of aerosols as drift is minimised by the installation of 'drift eliminators', which are required to minimise drift loss to less than 0.002% of the circulating flow rate, as required by AS/NZS 3666.1 (AZ/NZS 2002). The continual evaporation also results in a constantly increasing salt concentration, controlled by running water off from the tower, known as the 'bleed' or 'blow down', and replacing it from the mains supply. One disadvantage of this process is the loss and dilution of chemicals for water treatment such as biocides, corrosion and scale inhibitors.

Microbial Colonisation of Cooling Towers

Micro-organisms enter cooling towers through the mains supply, the intake of air or during cooling tower construction.

The constant fall of water within cooling towers acts as an efficient 'air scrubber' and introduces large amounts of organic, inorganic particulates and micro-organisms. Within cooling towers, the elevated water temperatures, high humidity and large surface areas provide ideal conditions for the growth of micro-organisms. The extent of microbial colonisation is variable and dependent on many environmental factors. Temperature, pH, salinity and chemical additives have all been demonstrated to influence colonisation (Bentham 1993).

Micro-organisms present in cooling towers can be separated into two distinct but related populations. Firstly the microbial flora in the planktonic phase which may be transient or actively multiplying, and secondly the microbial flora in biofilm. The development of biofilm within cooling towers accounts for the persistence of micro-organisms on surfaces. Organisms present in biofilm contribute the majority of biomass within cooling towers. The extent of biofilm formation directly influences the extent of colonisation in the planktonic phase (Bentham et al. 1993). Biofilm facilitates the development of localised environmental conditions on surfaces that are extremely different from the planktonic phase (Donlan et al. 2002). More importantly, biofilm provides a mechanism that inhibits the penetration of biocides and other chemical treatments to the contained cells (Gilbert et al. 2001). This mechanism can also support the existence of micro-organisms in environments where they might not normally survive.

Biofilm can readily detach from surfaces in response to water turbulence, changes in nutrient supply, chemical treatment, physical disturbances, microbial grazing and biological stimuli (Morgenroth & Wilderer 2000; Murga et al. 2001; Rice et al. 1999; Sawyer & Haermanowicz 1998). The detachment of biofilm provides microbial inocula for the circulating water phase and acts as a continuous seed. Biofilm detachment is actively promoted by intermittent cooling tower operation (Bentham & Broadbent 1993).

The types of micro-organisms found within cooling towers are diverse and include bacteria, algae, fungi, protozoa and viruses (Bentham 2000; La Scola et al. 2003; Shelton et al. 1994; Sungur & Cotuk 2005; Thomas et al. 2006). The majority are heterotrophic and require organic carbon as a nutrient and energy source. *Legionella* are commonly isolated from cooling towers and present significant implications for public health by their potential to cause disease (Fields et al. 2002).

Legionellae & Public Health

Legionella are gram negative bacteria that are ubiquitous in aquatic environments (Fliermans et al. 1981). They are motile, non-spore forming, fermentative obligate aerobes, are generally rod shaped with an optimum temperature for multiplication between 35°C and 37°C, and optimum pH for growth of 6.9 (Fields et al. 2002; Wadowsky et al. 1995). *Legionella* utilise amino acids as a carbon source and on primary isolation, have an absolute requirement for L-cysteine (Tesh & Miller 1981). The growth of *Legionella* can be stimulated by the presence of small amounts of minerals including iron, zinc, manganese, potassium, magnesium and copper (Devos et al. 2005; States et al. 1985).

There are 59 species of *Legionella* formally identified, with over 70 different serotypes recognised. Seventeen of these species have been identified or implicated as causative agents of Legionellosis, including Legionnaires' disease and Pontiac fever (Little 2003). The mode of transmission of *Legionella* from cooling towers is through the inhalation of aerosolised organisms; for example, from the inhalation of cooling tower drift (Yu 1993). The person to person transmission of *Legionella* has never been documented. *Legionellae* are able to resist destruction by macrophages in the human lung, which significantly aids their pathogenicity. The virulence of *Legionella* varies widely between the species, serogroups and strains (Yu et al. 2002). *Legionella pneumophila* is responsible for approximately 80% of cases of Legionnaires' disease and approximately 2-15 % of pneumonia cases requiring hospitalisation (Rusin et al. 1997). *L. pneumophila* has 16 serogroups identified, the majority of which are not associated with disease. *L. pneumophila* serogroup 1 is responsible for the majority of Legionellosis worldwide and is the primary causative agent of Legionnaires' disease (Yu et al. 2002). Disease from cooling towers is almost exclusively attributable to *L. pneumophila* serogroup 1 (Fields et al. 2002).

Legionnaires' disease is a severe pneumonia that might result in multi-organ failure. It was first described after an outbreak of pneumonia affecting 182 delegates at an American Legion conference in Philadelphia during 1976 (Fraser et al. 1977). The outbreak caused the deaths of 29 people and epidemiological investigations attributed the outbreak to *L. pneumophila*. Legionnaires' disease has an incubation period between 1 and 14 days (Little 2003). Clinical presentation of the disease ranges from mild respiratory symptoms to a severe atypical pneumonia. Early symptoms include coughs, headache, malaise and fever. With disease progression, these symptoms might be followed by neurological abnormalities, gastrointestinal symptoms, chest pain, respiratory distress and organ failure. Disease is more common in males, in adults over 50 years of age, in smokers, in people with a high alcohol intake, in the immunosuppressed and in those with existing pulmonary disease (Guiguet et al.1987; Little 2003; Marston et al. 1994).

Pontiac fever is a non-pneumonic infection also caused by respiratory exposure to *Legionella*. Symptoms are similar to influenza and might include fever, tiredness, myalgia, arthralgia, headache, cough, sore throat and nausea. Pontiac fever has an incubation period of between 5 and 66 hours, demonstrates a significantly higher attack rate, however, is self-limiting and those infected fully recover. Four species of *Legionella* have been implicated as the cause of Pontiac fever: *L. pneumophila*, *L. micdadei*, *L. feeleii* and *L. anisa* (Castor et al. 2005; Fields et al. 1990; Fields et al. 2001; Herwaldt et al. 1984). It has been postulated that Pontiac fever originates from a hypersensitivity pneumonitis due to the inhalation of *Legionella* cells, rather than to the actual infection (Rowbotham 1986).

Legionellosis in Australia

In Australia, contaminated cooling towers are largely responsible for Legionellosis outbreaks. The Melbourne Aquarium was the largest outbreak of Legionnaires' disease in Australia to date (Greig et al. 2004). Over a 14-day period in April 2000, 125 cases of Legionnaires' disease occurred as a result of contamination of the Aquarium's cooling towers with *Legionella*. *Legionella* including *L. pneumophila* were reported at concentrations in the order of 10^3 - 10^4 cfu/mL. An estimated 95 people were hospitalised with the disease and four deaths resulted. During this period there were approximately 83,500 visitors to the newly opened Aquarium, equivalent to a crude attack rate of 0.13% (Greig et al. 2004). The Australian states with the highest notification rates of Legionellosis over the last three years include South Australia, Western Australia and Victoria (National Notifiable Disease Surveillance System [NNDSS] 2006). Notified cases of Legionnaires' disease in South Australia and Western Australia are predominantly associated with potting mix and compost exposure (*L. longbeachae*), rather than cooling water systems and other sources (Spencer 2005).

The concentrations of *Legionella* found in cooling towers associated with illness are extremely variable and range between 10^3 and 10^6 cfu/mL (Greig et al. 2004; Shelton et al. 1994). There have been no relationships detected between concentrations of heterotrophic bacteria and *Legionella*. High concentrations of *Legionella* have been isolated from cooling towers which demonstrated no visible evidence of contamination and reported low plate counts (Bentham & Broadbent 1993). *Legionella* has also been shown to have symbiotic relationships with some algae and cyanobacteria (Bohach & Snyder 1983; Tison et al. 1980). Fields (2002) also reported that *L. pneumophila* was unable to grow and multiply in biofilm in the absence of protozoa. In contrast, Surman et al. (2002) demonstrated *L. pneumophila* could proliferate in biofilm in the absence of protozoa. These reports indicate that *Legionella* are opportunist organisms adapted to heterotrophic communities from which they derive their organic requirements. This in turn suggests that a number of mechanisms might operate in the colonisation and multiplication of *Legionella* in cooling towers. Effective control must address each of these survival strategies.

Protozoa in Cooling Towers

Cooling tower waters with their typically high microbial load provide ideal conditions for colonisation by free living protozoa including amoebae, ciliates and flagellates (Barbaree et al. 1986; Newsome et al. 1998). Free living protozoa feed predominantly on bacteria, fungi and algae and organic detritus through phagocytosis (engulfment). However, some micro-organisms have evolved that are able to evade protozoan predation (Matz & Kjelleberg 2005). These organisms are either not able to be ingested by protozoa or are able to survive, multiply and exist within the protozoa after internalisation. *Legionella* demonstrates this capacity and can survive and multiply in the cytoplasm of free living protozoa (Abu Kwaik et al. 1998). In response to environmental variables, this endocytic relationship might range from commensalism to parasitism.

Protozoa including *Naegleria*, *Hartmanella*, *Vahlkampfia*, *Acanthamoeba*, *Tetrahymena* and *Cyclidium* spp. have been extensively isolated from cooling tower waters (Newsome et al. 1998). Within cooling towers, protozoa are primarily found in association with biofilm on surfaces, sediment or microbial flocs. Surface grazing ciliates are almost exclusively found in association with biofilm (Huws et al. 2005). Amoebae readily expel vesicles from within the cell, especially prior to encystment. Vesicles expelled by amoebae do not adhere to surfaces and generally exist free in solution. Grazing by protozoa can produce rapid changes in the morphological and taxonomical properties of both biofilm and planktonic communities (Hahn & Hofle 2001). The spatial distribution of protozoa within biofilm is also complex. Some protozoa possess the ability to 'burrow', which might relate to their survival in biofilm (Huws et al. 2005). The temperatures that favor the growth of *Legionella* might also provide optimum conditions for the proliferation of protozoa (Berk et al. 2000). Protozoa have growth rates similar to bacteria and can multiply exponentially in short time periods. Adverse environmental conditions such as changes in temperature, pH, osmotic pressure and nutrient supply can stimulate some amoebae to encyst (Byrne & Swanson 1998). Cysts are walled dormant cells that might remain viable in the environment for many months, and can excyst again when conditions become favourable.

There are at least 13 species of amoebae and 2 species of ciliated protozoa that support intracellular replication of *Legionella* (Little 2003; Newsome et al. 1998). In many outbreaks of Legionnaires' disease, protozoa capable of harbouring *Legionella* have been isolated from the reservoir of infection (Barbaree et al. 1996; Fields et al. 1990). The encapsulation of *Legionella* within protozoa can provide protection from the external environment within cooling towers, including protection from biocides. Garcia et al. (2007) reported intracellular *L. pneumophila* within *A. polyphaga* was resistant to 1024 ppm sodium hypochlorite. Following intracellular replication, *Legionella* cells exhibit a dramatic increase in resistance to conditions such as high temperatures, acidity and high osmolarity (Byrne & Swanson 1998; Abu Kwaik et al. 1997). *Legionella* released from protozoa has been reported to have significantly different morphological and chemical characteristics compared to cultured cells, demonstrating more resistance to antimicrobial agents (Cirillo & Tompkins 1994; Greub & Raoult 2003). Relationships between *Legionella* and protozoa might also be species dependent (Fields et al. 1990). The virulence of *L. pneumophila* is also maintained or even increased when grown in co-culture with amoebae (Neumeister et al. 2000). Although the regulation of virulence factors in *Legionella* is not fully understood, the potential for protozoa to increase the virulence of *Legionella* has serious public health implications. Changes in the osmolarity of cooling tower water have been suggested to increase the intracellular replication within protozoa, which might produce populations more tolerant of cooling tower environments (Neumeister et al. 2000).

Chemical Control of Protozoa

Chemical treatments applied to cooling towers include biocides to inhibit microbial growth, dispersants, corrosion and scale inhibitors. Chemical biocides include metals, oxidising, non-oxidising antimicrobials and other agents such as surfactants and dispersants. Active ingredients of oxidising biocides include chlorine, bromines, chlorine dioxide, monochloramine, ozone and hydrogen peroxide. Non-oxidising biocides commonly include quaternary ammonium compounds, isothiazolinones, halogenated amides, guanidines, thiocyanates, thiocarbamates, halogenated glycols, aldehydes and other organic formulations. Dispersants, corrosion and scale inhibitors might include metals such as molybdenum, zinc and chromium, organics and phosphate polymers. Some of these chemicals might be stimulatory to *Legionella* growth and have the potential to influence biocide performance (States et al. 1985).

Biocides that have demonstrated activity towards protozoa include ozone, peroxides, chlorine, halogenated bisphenols and guanidines (Barker et al. 1992; Cursons et al. 1980; Kuchta et al. 1993; Sutherland & Berk 1996). Bromines have demonstrated some activity towards vesicles from protozoa, but recent reports suggest application of these formulations might be ineffective in spa pools (Surman-Lee & Bentham 2006). However, previous research has suggested cooling tower biocides might not always have desirable effects on protozoa. Srikanth and Berk (1994) reported the exposure of *A. hatchetti* and *Cochliopodium bilimbosum* to thiocarbamate, quaternary ammonium and isothiazolinone biocides increased their resistance upon exposure to other biocides. There are also significant differences between the efficiency of cooling tower biocides to amoebae in non-cysted and encysted forms. Trophozoites have far greater susceptibility to biocides than cysts (Sutherland & Berk 1996). Cysts of *Acanthamoeba* spp. have been reported to survive disinfection by free chlorine up to 40 mg/L, far greater than concentrations employed *in situ* (De Jonckheere & van De Woorde 1976). Encystment can also provide significant protection if *Legionella* cells are contained during this process. *Legionella* cells encysted within *Acanthamoeba* spp. have been demonstrated to survive disinfection by chlorine at 50mg/L (Kilvington & Price 1990).

Research has demonstrated that amoebae expel vesicles containing *Legionella* and other bacteria prior to encystment (Berk et al. 1998). Ciliates also expel vesicles during active grazing of biofilm (Berk et al. 1998). Vesicle production might be stimulated by the presence of cooling tower biocides, which encourage amoebae to encyst (Sutherland & Berk 1992). The expelled vesicles containing *Legionella* might also demonstrate some resistance to biocides. Berk et al. (1998) investigated the resistance of *L. pneumophila* contained in vesicles produced by two *Acanthamoeba* species against non-oxidising biocides. After exposure to recommended dosing concentrations for contact times of 4 and 24 hours, the viability of *L. pneumophila* cells was still maintained. This has important public health implications as vesicles have been reported to contain up to 10^4 bacteria and the exposure dose of *Legionella* from inhalation of cooling tower drift is potentially increased (Rowbotham 1986). Rowbotham (1986) proposed that the mechanism of infection for Legionnaires' disease was through the inhalation of protozoa or vesicles containing concentrated *Legionella* cells as opposed to individual cells.

The effects of biocides against protozoa have also been reported to be species variable, which might have ramifications considering the microbial diversity of cooling towers (Cursons et al. 1980). Many of the published biocide assessments have also been performed under axenic and controlled laboratory conditions using laboratory strains, and are unlikely to be comparable to conditions in cooling towers. There is little known about biocide performance in the presence of chemical treatments such as scale and corrosion inhibitors, which might have antagonistic or synergistic effects. *In situ*, the chemical and physical characteristics of the water and the engineered environment, including water temperature and pH, will additionally influence the effectiveness of biocides. The chemical control of protozoa in the presence of biofilm has been the subject of limited investigation (Brown & Barker 1999). Successful control will necessarily address both planktonic and sessile populations of microorganisms in the system.

Conclusion

The presence of *Legionella* in cooling towers presents significant implications for public health. Protozoa are likely to contribute to the survival of *Legionella* and their control has been proposed as a major method for minimising *Legionella* proliferation. Little effort has been directed towards the synergistic or antagonistic effects of chemical treatments in cooling tower microbial control. Cooling water systems are complex microbial ecosystems in which predator-prey relationships play a key role in dissemination of *Legionella*, leading to public health risk. Understanding the relative physical, chemical and biological contributions to these ecosystems is the pre-requisite for providing informed management strategies to protect public health.

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The Presence of *Legionella* Bacteria in Public Water Features

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The presence of Legionella *bacteria in public water features was studied[1]. During the summer months between December 2004 and February 2005, water samples were collected on four different occasions from each of seven sites in Wellington, New Zealand. The sites included a waterfall, three water fountains, two water ponds and a duck pond. Each water sample was tested for free available chlorine (FAC), total available chlorine (TAC), the presence/absence of* Legionella *bacteria using culture plates, direct fluorescent antibody test (DFAT), and polymerase chain reaction (PCR) targeting the 16s rRNA gene for* Legionella *bacteria. In five sites where chlorine was used, FAC levels varied from 0.0-6.4 ppm. Culture and DFAT tests were negative for* Legionella bacteria. *However, samples from five sites were positive for genus-specific* Legionella *DNA fragments using PCR. DNA sequencing studies of positive PCR products showed the probable presence of mixed species of* Legionella pneumophila, L. birminghamiensis, L. dumoffi, L. rubrilucens *and* L. waltersii. *These findings suggest that* Legionella *bacteria can be found in public water features and could be potential reservoirs of infection.*

Key words: Legionella; *Polymerase Chain Reaction; Water Features; DNA Sequencing*

Legionella bacteria are commonly found in fresh water environments, and clinical illness can also be attributed to their growth in man-made structures like cooling towers and within water distribution systems (Lin et al. 1998; Steinert, Hentschel & Hacker 2002; Young et al. 2005). Legionnaires' disease, a potentially fatal respiratory illness is caused by the *Legionella* bacteria. The disease is fatal in about 12% of previously healthy people, and higher in immunocompromised persons (Bates et al. 2000).

In New Zealand the majority of cases of Legionnaires' disease are sporadic pneumonias with the source of the infection identified in only about 10 to 20% of cases. The infrequent identification of a source might in part be attributable to incomplete sampling due to not recognising important infection sources. A number of studies have indicated the presence of *Legionella* species in domestic water supplies (Alary & Joly 1991; Stout et al. 1992). In a study of domestic hot water systems in Wellington households no viable *Legionella* species were isolated by culture (Bates et al. 2000), although these are recognised as significant infection sources.

Overseas studies have shown that *Legionella*-contaminated water features like decorative fountains and waterfalls can contribute to the outbreak of legionellosis in the community (Daly 2005; Heng et al. 1997; Hlady et al. 1993; Jones et al. 2003;). As there is no previous documented study of the presence of *Legionella* species in public water features such as water fountains, waterfalls and ponds in New Zealand, we decided to study the presence of *Legionella* bacteria in such water features and their potential as reservoirs of infection for legionellosis.

Methods

Sampling

Seven public water features operated by Wellington City Council (WCC) were tested during our warm summer months from December 2004 to February 2005. The water features studied included a waterfall pond, three water fountains, two water ponds and a duck pond.

These seven sites were each sampled on four different occasions during the study period. A total of 28 samples were collected for chemical and *Legionella* tests. During each sampling run, one water sample per site was collected in a sterile bottle for *Legionella* test. Water samples were delivered to the laboratory for *Legionella* testing in an insulated container to minimise temperature variations (AS/NZS 1998). For each sample collected, on-site measurements for water temperature, free available chlorine (FAC) and total available chlorine (TAC) were undertaken.

Chemical FAC/TAC

FAC and TAC were measured by using a portable DR100 colorimeter for pH/chlorine (HACH, CO, USA). Results registered on the colorimeter were recorded as mg/L or parts per million (ppm).

Microbiological analysis

Culture

Each 1000mL water sample was filter-concentrated to 10mL with a 0.45µm nylon membrane filter. The concentrated sample was acid-treated, and 100µL was spread-plated onto buffered charcoal yeast extract agar (BCYEα) and BCYEα with GVPC selective supplement (Global Science, Auckland) for *Legionella* bacteria isolation. 100µL of concentrated, non-acid-treated sample was also spread-plated similarly. The plates were then incubated in a humid atmosphere at 37°C and examined at least twice during a ten-day incubation period.

Presumptive *Legionella* colonies were subcultured onto blood agar (BA)(Fort Richard, Auckland) and BCYE agar (B+) and BCYE agar without L-cysteine (B-). Growth on BA indicates non-*Legionella* bacteria. No growth on BA, B-, but growth on B+ indicates presumptive *Legionella*.

DFAT

10µL aliquots of filter-concentrated sample were fixed to slides and stained with mTechTM fluorescein-conjugated anti-*Legionella* antibodies (Monoclonal Technologies, Alpharetta, GA, USA). Each slide was viewed with the epi-fluorescent microscope (Olympus BX60, Olympus NZ) at 400x magnification. Apple-green, rod-shaped cocci-bacilli or long rod-shaped bacilli indicates presence of *Legionella* bacteria. Absence of the apple-green bacilli indicates no *Legionella* bacteria present.

Molecular tests PCR & DNA sequence analysis

One mL of the sample concentrate was used for genomic DNA extraction, and *Legionella* genus-specific polymerase chain reaction (PCR). Total DNA extraction was performed by using Roche blood/bone marrow/tissue kit (magnetic glass particles) (Roche Applied Sciences, Auckland). Hot-start PCR was with 16S genus-specific *Legionella* primers (Invitrogen, Auckland). Gel electrophoresis was used to detect the ~730bp PCR product. Absence of a ~730bp product indicates no Legionella being amplified. When a ~730bp product was present, DNA sequencing was used to identify it.

The PCR product was cleaned up and DNA sequence reactions carried out using ABI Big Dye Terminator v3 (Applied Biosystems, Melbourne) in both the forward and reverse directions. ABI Sequence Navigator (Applied Biosystems, Melbourne) was utilised in DNA sequence analysis to construct a consensus DNA sequence from the forward and reverse sequences obtained. The identity of the sequence was deduced via EMBL search. Genus-specificity was based on >97% DNA sequence homology. Species-specificity was based on DNA sequence >99% homology.

Results

Culture, DFAT & FAC

DFAT and culture tests were negative for all samples (Table 1). The temperature of water samples collected varied from 15-22°C. In sites where chlorine was used, the free available chlorine (FAC) ranged from 0.0 - 6.4 ppm.

Samples from sites #4 (Waterfall pond) and #7 (Duck pond) where many ducks swim were heavily contaminated with faecal organisms.

PCR & DNA sequence analysis

There were 10 samples in which the PCR test was positive for *Legionella* bacteria (Table 1). These *Legionella*-positive PCR products were from sites # 1, 2, 3, 4 and 5. DNA sequencing analysis of these positive PCR products suggested mixed *Legionella* species in 9 products, but in 1(site #1, sampled 6 Jan 2005) it was a short clean *Legionella pneumophila* subspecies sequence product (Table 2).

Table 1: Chemical and microbiological analysis of water samples from public water features

Sample ID	Site Description	Site #	Sampled	DFAT	Culture	PCR	Temp °C	FAC	TAC
ENM04/246	Pond	1	8-Dec-04	neg	neg	positive	18	5.2	5.2
ENM04/247	Water bucket fountain	2	8-Dec-04	neg	neg	positive	15	2.8	2.8
ENM04/248	Water cascade pond	3	8-Dec-04	neg	neg	positive	16	0.1	0.1
ENM04/249	Waterfall pond	4	8-Dec-04	neg	neg	neg	16	0	0
ENM04/250	Water fountain	5	8-Dec-04	neg	neg	neg	17	0.8	1.1
ENM04/251	Water fountain	6	8-Dec-04	neg	neg	neg	18	0	0
ENM04/252	Duck pond	7	8-Dec-04	neg	neg	neg	16	0	0
ENM05/001	Pond	1	6-Jan-05	neg	neg	positive	19	6	7.6
ENM05/002	Water bucket fountain	2	6-Jan-05	neg	neg	neg	16	2.1	2.3
ENM05/003	Water cascade pond	3	6-Jan-05	neg	neg	positive	17	0.5	0.6
ENM05/004	Waterfall pond	4	6-Jan-05	neg	neg	neg	17	0	0
ENM05/005	Water fountain	5	6-Jan-05	neg	neg	neg	18	0.3	0.4
ENM05/006	Water fountain	6	6-Jan-05	neg	neg	neg	19	1	1.1
ENM05/007	Duck pond	7	6-Jan-05	neg	neg	neg	17	0	0
ENM05/014	Pond	1	20-Jan-05	neg	neg	positive	18	0	0
ENM05/015	Water bucket fountain	2	20-Jan-05	neg	neg	positive	16	1	1.7
ENM05/016	Water cascade pond	3	20-Jan-05	neg	neg	neg	17	0.6	0.7
ENM05/017	Waterfall pond	4	20-Jan-05	neg	neg	positive	17	0	0
ENM05/018	Water fountain	5	20-Jan-05	neg	neg	positive	18	0	0.1
ENM05/019	Water fountain	6	20-Jan-05	neg	neg	neg	19	0.3	0.3
ENM05/020	Duck pond	7	20-Jan-05	neg	neg	neg	16	0	0
ENM05/059	Pond	1	10-Feb-05	neg	neg	neg	22	6.4	14.4
ENM05/060	Water bucket fountain	2	10-Feb-05	neg	neg	neg	19	2.4	3.4
ENM05/061	Water cascade pond	3	10-Feb-05	neg	neg	neg	21	2.8	8
ENM05/062	Waterfall pond	4	10-Feb-05	neg	neg	positive	21	0	0
ENM05/063	Water fountain	5	10-Feb-05	neg	neg	neg	20	1.7	2.6
ENM05/064	Water fountain	6	10-Feb-05	neg	neg	neg	21	0.7	0.9
ENM05/065	Duck pond	7	10-Feb-05	neg	neg	neg	19	0	0

DFAT - direct fluorescent antibody test

PCR - polymerase chain reaction

FAC - free available chlorine

TAC - total available chlorine

Table 2: Sequencing analysis of positive Legionella PCR products

Site #	Sampled	DNA sequence	% homology	Sample condition on sequencing	Closest ID from EBI¶ (EMBL Accession #)
1	8-Dec-04	*L.birminghamiensis*	96.15%	Mixed legionella species present	S#1 (Z49717)
2	8-Dec-04	*L.birminghamiensis*	95.77%	Mixed legionella species present	S#2 (Z49717
3	8-Dec-04	*L.rubrilucens*	95.50%	Mixed legionella species present	S#3 (Z32643)
1	6-Jan-05	*L.pneumophila*	99.79%	Short clean sequence product	S#4 (AE017354)
3	6-Jan-05	*L.dumoffii*	98.23%	Mixed legionella species present	S#5 (Z32637)
1	20-Jan-05	*L.pneumophila*	97.54%	Mixed legionella species present	S#6 (AE017354)
2	20-Jan-05	*L.waltersii*	95.09%	Mixed legionella species present	S#7 (AF122886)
4	20-Jan-05	*L.birminghamiensis*	95.91%	Mixed legionella species present	S#8 (Z49717)
5	20-Jan-05	*L.pneumophila*	96.59%	Mixed legionella species present	S#9 (CR628336)
4	10-Feb-05	*L.pneumophila*	96.85%	Mixed legionella species present	S#10 (CR628337)

EBI : European Bioinformatics Institute

S #1: LBIRMSSRN Z49717.1 L. birminghamiensis, *partial 16S rRNA gene (1467 nt) with 96.154% identity (96.154% ungapped) in 676 nt overlap (1-676:416-1091)*

S #2: LBIRMSSRN Z49717.1 L. birminghamiensis, *partial 16S rRNA gene (1467 nt) with 95.771% identity (95.771% ungapped) in 733 nt overlap (1-733:416-1148)*

S #3: LR16SRRN Z32643.1 L. rubrilucens *strain WA-270A-C2, partial 16S rRNA gene (1456 nt) with 95.504% identity (95.634% ungapped) in 734 nt overlap (1-734:443-1175)*

S #4: AE017354 AE017354.1 L. pneumophila *subsp. pneumophila strain Philadelphia 1, complete genome (3397754 nt) 99.787% identity (99.787% ungapped) in 469 nt overlap (1-469:608935-609403)*

S #5: LD16SRRN Z32637.1 L. dumoffii *(NY-23) partial 16S rRNA gene, (1418 nt) 98.229% identity (98.363% ungapped) in 734 nt overlap (1-734:404-1136)*

S #6: AE017354 AE017354.1 L. pneumophila *subsp. pneumophila strain Philadelphia 1, complete genome (3397754 nt) 97.411% identity (97.544% ungapped) in 734 nt overlap (1-734:360311-361043)*

S #7: AF122886 AF122886.1 L. waltersii *partial 16S rRNA gene, (1447 nt) 95.089% identity (95.089% ungapped) in 733 nt overlap (733-1:280-1012)*

S #8: LBIRMSSRN Z49717.1 L. birminghamiensis *partial 16S rRNA gene, (1467 nt) 95.913% identity (96.044% ungapped) in 734 nt overlap (1-734:416-1148)*

S #9: CR628336 CR628336.1 L. pneumophila *strain Paris complete genome, (3503610 nt) 96.594% identity (96.726% ungapped) in 734 nt overlap (734-1:3188641-3189373)*

S #10: CR628337 CR628337.1 L. pneumophila *strain Lens complete genome, (3345687 nt) 96.854% identity (96.854% ungapped) in 731 nt overlap (731-1:3046985-3047715)*

Discussion

The positive results of *Legionella* genus-specific PCR analysis would suggest the presence of *Legionella* bacteria in five of the water features tested (Table 1). DNA sequencing analysis of these *Legionella*-positive PCR products indicated mixed *Legionella* species in all but one of them. It is not totally unexpected that mixed species of *Legionella* are found in these sites since they are public water features out in the open environment (Table 1).

The sampling procedures used in this study might have contributed to the low number of positive results obtained. The 1-L water samples would bias the sampling to planktonic *Legionella*, whereas in their natural habitat, sessile *Legionella* associated with surface biofilms might be where the bacteria is more likely to be found (Atlas 1999; Hoebe & Kool 2000). When designing the sampling procedures it was argued that if *Legionella* were present in sufficient numbers to be a public health concern, then standard quantitative *Legionella* culture would be sufficient to detect their presence. Their absence by culture might reflect a low risk (Table 1).

The water temperature of samples measured varied from 15°C - 22°C (Table 1). Although not in the normal range for *Legionella* growth, it is assumed the bacteria might still be capable of some growth in the aqueous environments studied. *Legionella* have complex growth requirements, which include a supply of the essential amino acid L-cysteine. In their natural habitat, this amino acid is supplied either by other microorganisms with which they are associated in the biofilm, or in their protozoan host. In tropical countries where the ambient temperatures are higher than in New Zealand, the *Legionella* growth conditions would be enhanced in such public water features (Heng et al. 1997).

In four of the five sites where water samples yielded positive genus-specific *Legionella* PCR products, free available chlorine (FAC) level ranged from 0.0 - 6.0 ppm. Continuous disinfection of potable water with FAC level of 1-2 mg/L is effective against *Legionella* bacteria (Pearson 2000). The use of chlorine tablets to disinfect the water used in the water features would have contributed significantly to the decreased growth of *Legionella* bacteria as evidenced by the negative culture and DFAT tests (Table 1). Some protozoa in the environment provide nutrients, protection and intracellular growth opportunities for *Legionella* bacteria. Stress due to the chlorine treatment might also inhibit the culture of viable *Legionella* bacteria. In sites #4 (Waterfall pond) and #7 (Duck pond), the overwhelming presence of faecal microorganisms in the samples collected might have suppressed or inhibited the growth of *Legionella* bacteria in the culture test (Table 1).

At this stage, the mixed *Legionella* sequences that are detected from DNA sequencing analysis of PCR products are unable to be definitely classified. Additional work needs to be undertaken to define these mixed sequences. Molecular tests are more sensitive than the DFAT or culture tests for environment samples where the amount of *Legionella* bacteria present may be low (Atlas 1999).

The presence of genus-specific *Legionella* PCR DNA products suggests the possible presence of viable *Legionella* bacteria in five of these public water features. Additional work is required to equate positive PCR DNA results with actual viable bacteria and public health risk. Overseas studies have identified *Legionella pneumophila*, *Legionella longbeachae* and *Legionella bozemanii* as major causal species of community-acquired legionellosis (O'Connor et al. 2007; Yu et al 2002). Our results showed that of the 10 samples with genus-specific *Legionella* PCR DNA products, four samples showed the presence of *Legionella pneumophila* DNA sequences (Table 2).

Active chlorination is useful and essential in decreasing the growth of *Legionella* bacteria as these sites remain possible reservoirs of infection, and are in close proximity to the public, especially during the warm summer months. *Legionella* bacteria can be transmitted in aerosols (Nguyen et al. 2006; O'Connor et al. 2007) and these sites are possible sources of aerosols. Therefore, it is important that such public water features are regularly cleaned to prevent the growth of *Legionella* bacteria in the aqueous environment. However, aerosols generated from *Legionella*-contaminated cooling towers in well populated areas (Canterbury District Health Board [CDHB] 2005; Greig et al. 2004) would be of more public health concern than water features in sparsely populated areas.

Conclusion

The presence of *Legionella* bacteria was detected in five out of seven public water features studied in Wellington based on PCR and DNA sequencing analysis. Such public water features remain potential reservoirs of infection for legionellosis. Regular maintenance, active chlorination and monitoring of water in public water features is an essential preventative procedure to minimise the transmission of aerosols of infectious *Legionella* bacteria to the public.

Endnote

1. This study was presented in part to the 106th General Meeting of the American Society for Microbiology in Orlando, Florida, USA, 21-25 May, 2006

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Human Psittacosis Associated with Purchasing Birds from, or Visiting, a Pet Store in Newcastle, Australia

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Between December 2004 and July 2006, five confirmed and one probable human psittacosis case were notified to the Hunter New England Population Health Unit. All five cases had been exposed to caged birds from the same pet store. A public health investigation identified a number of high risk practices at the implicated pet shop. We discuss the results of the investigation, which demonstrate the need for clarifying the roles and responsibilities of various agencies that have an interest in reducing risk practices associated with pet stores and ask how widespread practices that increase the risk of human psittacosis might be in Australian pet stores.

Key Words: *Psittacosis; Ornithosis; Pet Store;* Chlamydophila Psittaci; *Public Health; Australia*

Chlamydophila psittaci (formerly known as *Chlamydia psittaci*) can be transmitted from birds to humans through inhalation of the agent from desiccated droppings, secretions, or dust from the feathers of infected birds. In humans the resulting infection is referred to as psittacosis, also known as parrot disease, parrot fever or ornithosis (Centers for Disease Control 2000). Psittacosis infection in humans before the onset of illness has an incubation period of between 4-15 days. The infection can cause a range of symptoms ranging from an unapparent illness to a systemic illness with severe pneumonia. Fever, headache, rash, myalgia and chills might be present. Respiratory symptoms are often mild with an initial non-productive cough. Pleuritic chest pain is uncommon. Complications that might occur include encephalitis, myocarditis, thrombophlebitis and life-threatening pneumonia. Psittacosis infection in humans and animals is a notifiable condition in New South Wales (*Public Health Act 1991* and *Stock Diseases Act 1923* respectively). Population Health Units in NSW are required to investigate notifications of human disease to establish the likely source of infection and identify common sources of exposure that might represent ongoing risks to the health of the public (Psittacosis - NSW Response Protocol for NSW Public Health Units 2004).

C.psittaci is most commonly identified in psittacine birds such as parrots, macaws, cockatiels and parakeets (Centres for Disease Control [CDC] 2000). However, other orders like the Lariformes (gulls), Anseriformes (ducks) have been found to be a significant avian host (Kaleta & Taday 2003). It is important that all possible significant sources, including animals other than birds need to be considered in epidemiological investigations of human cases. Birds may appear healthy but be carriers of *C.psittaci* and can shed the organism intermittently. Exogenous and endogenous stress factors, such as transport, crowding, chilling, breeding and debilitating factors associated with other organisms or genetic predisposition can activate shedding among apparently healthy birds. Palmer, Lord Soulsby and Simpson (1998) state that *C.psittaci* is 'stable in dust, feathers, faeces and products of abortion at ambient temperatures, an ecologically important factor in transmission' (p.57). They also report that 'infectivity has been documented in canary feed for 2 months, in poultry litter for up to 8 months, straw and hard surfaces for 2-3 weeks and in diseased turkey carcasses for more than 1 year' (Palmer, Lord Soulsby & Simpson 1998, p. 57).

Notification of Human Disease Linked to a Pet Store

Between December 2004 and July 2006, five confirmed cases and one probable human psittacosis case were notified to Hunter New England Population Health Unit (HNEPH) from the Greater Newcastle area. All confirmed cases met the three case definition requirements including laboratory, clinical and epidemiological evidence conforming to the Australian national notifiable diseases case definition for psittacosis (Department of Health and Ageing 2004). All developed clinical illness within the established incubation period for human psittacosis after visiting a local pet store housing caged birds or after purchasing birds from the store. All cases were interviewed for other possible sources of exposure including personal bird ownership and pet bird contact, occupational and recreational pursuits with exposure to wild or domestic birds or bird faeces, exposure to birds in other pet stores or bird traders, and exposure to friends or relatives with birds during the incubation period. The five confirmed cases demonstrated a greater than four-fold rise in antibody titre against *C.psittaci* with repeat testing two weeks at the same laboratory after the initial test, while the probable case had a compatible clinical illness with a single high antibody titre against *C.psittaci* - Table 1 (Department of Health and Ageing 2004; Psittacosis - NSW Response Protocol for NSW Public Health Units 2004).

Table 1: Human psittacosis cases from Greater Newcastle area linked to the pet store

Case No:	Month of onset	Laboratory result	Case status	Nature of exposure
1	Dec 2004	Fourfold rise in antibody titre (titre >512)	Confirmed	Visited pet shop daily prior to the onset of illness
2	Oct 2005	Fourfold rise in antibody titre (titre >512)	Confirmed	Visited pet shop for an extended period prior to the onset of illness
3	Dec 2005	Fourfold rise in antibody titre (titre >512)	Confirmed	Cockatiel purchased at pet store two weeks prior to onset of illness. Cockatiel died at case's home, with an unknown cause and unknown date of death. Case was also exposed to wild birds and had an existing pet bird with no apparent symptoms.
4	Feb 2006	Fourfold rise in antibody titre (titre >512)	Confirmed	Regularly visits to pet store (approximately every 2 weeks including during the incubation period before onset of illness). No recent bird purchase.
5	June 2006	Fourfold rise in antibody titre (titre >512)	Confirmed	Cockatiel purchased at pet store four weeks prior to disease onset and transported home in car. Bird appeared well and housed in a cage in case's bedroom. Case was also exposed to wild birds at home with an outside bird feeder in use for 10 years.
6	June 2006	Single high antibody level	Probable	Father of case 5. Cockatiel purchased at pet store four weeks prior to disease onset. Transported case 5 and bird home. Bird appeared well and housed in the bedroom of case 5. Case was also exposed to wild birds at home with an outside bird feeder in use for 10 years.

Environmental Investigation

The confirmed psittacosis case in December 2005 and subsequent confirmed case in February 2006 both identified the specific pet store as their only likely exposure. This prompted a review of all notifications of psittacosis by home address during the previous five year period from the Greater Newcastle area. On identifying two additional notified cases that had also noted significant exposures to the same pet store or purchased birds from the store prior to the onset of illness, during a period compatible with the known incubation period for *C. psittaci*, it was decided to conduct an environmental health assessment of the premises. The assessment was conducted by HNEPH Environmental Health Officers. At the time of this inspection several recommendations were made in writing for improving bird handling and cleaning practices. Of particular concern was the accumulation of faecal waste in cages, heavily faecal contaminated bird watering containers, no record keeping of bird suppliers, soiled carpet in the room housing the birds, the use of a vacuum cleaner, and observation of staff not utilising personal protective equipment when cleaning.

In June 2006, an additional confirmed and probable case that identified suggestive exposure to these premises prompted a further investigation. Environmental Health Officers from HNEPH and the Local Council conducted a joint risk assessment and follow-up investigation of the pet store. Due to the limited information available for public health and environmental investigations of human psittacosis in Australia and in pet stores an investigation tool was designed, based on information contained in the *Compendium of Measures to Control* Chlamydia psittaci *Infection among Humans* (CDC 2000). The development of the tool was to ensure coverage of all relevant aspects of public health risk, including stock supply, bird deaths/illness and treatment, quarantining practices, husbandry practices, cleaning, sanitising, personal protective equipment (PPE) use, and other staff practices. The tool developed also permitted recording the source and location of environmental specimens and an area for a schematic diagram of the premises to be documented. For information on the tool, it is located at: <http://www1.hnehealth.nsw.gov.au/hneph/EnvironmentalHealth/PsittacosisOnsiteInvestigationForm.pdf>. Photographic evidence and environmental samples were also gathered at the premises.

Suppliers and records

The owner did not maintain a bird supplier register; thus there were no records of dates of bird purchases, bird species, supplier details or details of bird illness. Similarly, there was no record of bird sales. The owner advised that he had multiple suppliers ranging from large interstate suppliers to people who walked off the street and offered small numbers of birds, however, no formal records were kept. Assessment of newly acquired birds consisted only of visual observation checking for feather condition and weight, with birds only rejected if they had discharging eyes or appeared in poor condition.

Pet Store Stock, Quarantine and Husbandry Practices

There were 350 birds in 63 cages housed in the 'aviary room', which had an area of approximately 25m^2. The aviary room had a single door, no windows, no mechanical ventilation system, and a malodour. Bird species ranged from cockatoos, budgerigars, finches, cockatiels, galahs, short beaked corellas, and grass parrots. Although the proprietor admitted that there were several bird deaths each week, these were ascribed to bird attacks and not investigated further. There had been no veterinary consultations in relation to dead or ill birds. It was common practice for birds purchased by customers to be replaced within 7 days at half price if they died.

The pet shop had no policy or designated area for isolating or quarantining newly acquired birds or ill birds. The *Animal Welfare Code of Practice No 4: Keeping and Trading of Birds* recommends for health and hygiene purposes that 'newly acquired birds should be quarantined for a suitable time for treatment/ observation before release into aviaries or cages' (NSW Department of Primary Industry 2004, p. 4).

While quarantine might serve to reduce the risk of disease transfer from newly arrived sick birds, a practical quarantine period on its own would not be able to minimise the risk of *C. psittaci* from the newly arrived birds due to the inapparent carrier state. Additional measures such as appropriate medication during the quarantine period might reduce the risk significantly but might also lead to a build-up of antibiotic resistance. The most effective method to minimise the risk is the acquisition of birds only from reputable sources and regular health checks.

In the aviary room, bird cages were stacked on top of each other from floor to ceiling along three walls (Figures 1 and 2). Cages adjoined each other, were in close proximity and constructed of mesh with pull out solid tray bases. There were no solid barriers between cages to prevent potential transfer of infected matter between cages and no sand or other material under trays to prevent dust production.

Figure 1 Avian room

Figure 2: Avian room

Cleaning

Dry methods were employed (brooms, brushes, dustpans and scraper blades) for cleaning faeces from cages and a vacuum cleaner was used for removing bird faeces from carpets. These might be appropriate cleaning methods if staff were wearing PPE, however, this method was being used with members of the public present who were not wearing PPE. There was a small blue dust pan and broom in the aviary room used for sweeping feathers, seeds and faeces off the benches (Figure 3). There was a significant build-up of faecal matter in the majority of cages as well as in several food and water containers indicating irregular cleaning (Figure 4). Dedicated cleaning facilities were not available with cleaning performed in a blue plastic tub in the staff toilet (Figure 5). This area was inadequate for accommodating trays and cages to facilitate proper and easy cleaning, with water obtained from the small staff hand wash basin. The tub was stored in a soiled condition (Figure 6). The premises had no access to an outside garbage wash down area where effective cage cleaning could be performed.

No large wash up sink for cleaning large contaminated items was available in the pet store and draining/drying space to prevent re-contamination after washing was inadequate. Waste water was disposed into a toilet or uncovered floor waste drain. The sink had running hot water, however, there were no hand towels or soap provided to facilitate

Figure 3: Dust pan used in the avian room

Figure 4: Build up of faecal matter in cage

Figure 5: Single tub used to clean 63 cages

Figure 6: Faecal matter remaining on 'cleaned' wooden perches

effective hand washing after handling birds to prevent potential cross infection between sick and healthy birds.

Staff and personal protective equipment

The premises had dust masks available for staff, however, their location (behind the front counter and 30 meters away) did not facilitate easy and regular access for staff when cleaning. There were no disposable or non-disposable gloves available for cleaning and handling sick or dead birds. During the inspection, the owner removed a dead budgerigar from a cage using no personal protection and was not observed to wash his hands after handling the dead bird.

Environmental Samples

Eight samples were collected, including one dead green and yellow budgerigar, one packet of approximately 100g of bird litter (faeces, feathers, and bird seed husks) from the base of a cockatiel cage, four wet swabs from two separate galah cages, one short beaked corella cage and one grass parrot cage, one swab sample from debris in the blue wash up tub stored in the toilet area, and one swab from inside the vacuum cleaner (Figure 7). No cloacal swabs were collected as public health officers were not trained in this procedure. The owner was requested to engage an avian veterinary specialist to establish the health of resident birds.

Figure 7: Environmental samples and swabs for analysis

Environmental samples were transported at a temperature of 5°C to the Nepean Hospital, Microbiological Department. Environmental specimens were vortexed in 5 mls of water before DNA extraction. External bird specimens from the one cadaver received were collected from feathers, beak, cloaca and conjunctiva. DNA was extracted using QIA amp DNA mini Kit (www.Qiagen.com). Real Time Polymerase Chain Reaction (PCR) assay using three primer sets (one genus and two species specific) modified to real time format and performed on a Corbett 3000 platform (de Graves et al. 2003; Menard et al. 2006; Messmer et al. 1997). The product was identified using a genetic corresponding probe. Five of the eight environmental samples were positive for *C.psittaci* (Table 2).

Table 2: Sample and swab results

Nature of sample	Result
100 grams of bird litter (faeces, seed positive husks and feathers) from the cockatiel cage	
Swab 1 faeces in bottom of cage (Grass parrots)	positive
Swab 2 faeces in bottom of cage (Parrots)	negative
Swab 3 faeces in bottom of cage (Corellas short beak)	negative
Swab 4 faeces in bottom of cage (Rosella cross)	positive
Swab 5 base of blue tub used for cleaning	positive
Swab 6 inside panel of vacuum cleaner	positive
Dead green and yellow budgie	negative

Note: While environmental swabs can be taken from the premises, sampling from birds requires a trained veterinarian

Discussion

To our knowledge this is the first published paper of a psittacosis outbreak associated with a pet shop in Australia. A number of case reports, however, of human psittacosis associated with pet stores have been published internationally. These include two cases of *C.psittaci* infection occurring in employees at the same pet shop in Japan in 2001 (Maegawa et al. 2001), an outbreak of clinically mild psittacosis in humans from a shipment of birds supplied to nine pet stores in Atlanta in 1995 (Moroney et al. 1998), two cases of psittacosis in an elderly couple who ran a pet shop in Japan 2005 (Saito et al. 2005), an outbreak of seven people (two of whom died) with *C. psittaci* infection associated with a small town pet shop in Scotland (Morrison et al. 1991), and an outbreak in a small town in southwest Sweden from January 1967 to May 1969 with 13 of the cases having purchased birds from the same pet shop (Jernelius et al. 1975). The prevalence of psittacosis internationally suggests that the geographical prevalence in birds varies markedly, ranging from 6 to 15% in German pet shops, while *C.psittaci* was isolated from 50% of pet birds necropsied in California (Victorian Department of Primary Industry, undated). The prevalence of *C.psittaci* in Australian birds including shedding in pet shops found that most Chlamydia shedding birds appeared clinically normal in the survey (McElnea & Cross 1999). This presents some of the challenging aspects of prevention and control with quarantine measures alone being insufficient, although quarantine practices are useful for other bird diseases.

In NSW from 2002 to 2006 there were 532 notifications of human psittacosis of which 149 were from the Hunter New England (HNE) area (Notifiable Disease Database NSW Health Version 4.01). Almost a third of the reported cases in NSW occurred in 2002 (155 cases) and were associated with a possible psittacosis outbreak in the Blue Mountains linked to wild birds (Telfer et al. 2005). During this period the only identified cluster in HNE occurred in 2003 with the three affected people having visited another pet store, also located in Newcastle. The three cases included a pet store staff member, a person who had visited and purchased a bird, and a veterinarian who treated the birds and had no other bird exposures prior to illness (Carolyn Herlihy pers. comm.)

The lack of reported psittacosis among the pet store staff considering the identified risk practices associated with cleaning and other husbandry practices should be noted. However, asymptomatic infection in humans is common. Staff turnover and limited records of staff absenteeism prevented further exploration of the history of staff illness. *C.psittaci* infection in humans occurs considerably more frequently than is suggested by notification numbers (Gregory & Schaffner 1997).

Although *C.psittaci* was detected in this pet store, the presence of the organism is circumstantial rather than conclusive proof of causation. While the results indicating the presence of the *C.psittaci* in the environment do not conclusively demonstrate cause and effect, when considered together with the epidemiological and risk factor information from human cases and the identified high-risk practices in the pet store, they make a compelling case. The pet store owner was instructed to implement a comprehensive series of remedial actions and no additional cases have been notified.

Our investigation identified a number of high risk pet store practices relating to keeping and trading birds, including poor husbandry practices, limited selective purchase policy (will generally purchase from anyone), no quarantining or isolation practices, no system for tracking bird suppliers, inadequate ventilation of the aviary room, inadequate cleaning facilities and practices, inadequate staff practices regarding the use of personal protective equipment. The premises were not designed or constructed to facilitate the optimal operation as a pet store and practices required to prevent disease to humans were deficient.

The distribution of the notified cases over 18 months highlighted the difficulty of identifying the ongoing risk of a zoonotic pathogen using routine surveillance. Two previous contacts with the particular premises by different HNEPH Environmental Health Officers were not automatically linked by available surveillance systems. Investigations conducted initially were not standardised due to the non-availability of a standardised Australian risk assessment inspection tool. Thus, as mentioned above, an investigation tool called a 'Psittacosis environmental health investigation tool' based on the US CDC compendium was developed to standardise the local investigation.

The investigation revealed that there was no single regulatory governing body in NSW assessing public health risks associated with commercial aviaries and pet bird traders. The NSW Department of Primary Industry, Animal Welfare Branch authorises RSPCA officers to implement the Animal Welfare Code of Practice No 2 - Animals in Pet Shops, and the Animal Welfare Code of Practice No 4 - Keeping and Trading of Birds. However, the Codes of Practice generally relate to the health and welfare of birds and do not directly relate to protection of the public's health. WorkCover NSW is also authorised to inspect workplaces, however, in this situation as no employees were identified as cases Work Cover did not believe that this fell within its jurisdiction. Local Government has officers authorised under the *Local Government Act 1993* (NSW) to take action to prevent local health risks and nuisance, however, they do not routinely inspect pet stores.

As previously mentioned, a joint public health investigation was conducted by Local Government and Hunter New England Population Health (HNEPH). Environmental Health Officers at the state level are only authorised under the *NSW Public Health Act 1991*, while local government Environmental Health Officers are authorised under both the *NSW Public Health Act 1991* and the *NSW Local Government Act 1993*. The legislation delineates the responsibilities of Environmental Health Officers in Local Government for addressing issues relating to health. In terms of administering public health functions to protect public health the nuisance and order provisions in the *Local Government Act 1993* (NSW) are often the most appropriate and expedient to use at a local level. The powers under the *Public Health Act* are generally of State significance. However, it became evident that specific responsibilities in addressing this type of public health risk were not clear between Local Government, NSW Health, HNEPH and the NSW Department of Primary Industry. In addition, the *NSW Local Government Act 1993* removed the clause requiring that recognised Environmental Health Officers be employed as Environmental Health Officers within Local Government. The benefits of having formal environmental and public health risk assessment skills as well as working knowledge of the *Local Government Act* to address local health issues become apparent in this disease cluster investigation.

This investigation has identified a number of important agendas if the psittacosis risk associated with pet stores is to be adequately understood, prevented and managed. Successful public health interventions require integrated approaches in the legislation, guidelines and protocols, and training domains using a collaborative effort. In addition, more needs to be known of the infective, environmental and host factors leading to human infection so that preventative measures can be more effective.

Legislation

Within NSW it is necessary to strengthen the *NSW Public Health Act 1991* to respond to public health incidents at the local level to ensure public health is protected. The *NSW Local Government Act 1993* could also require local governments to ensure pet stores are premises requiring development consent and building approval and ensure that all pet store applications are referred to Council Environmental Health Officers for pre-emptively identifying potential public health risks related to construction, fit out and operation. It would also be useful to expand the scope of RSPCA inspection authorities beyond simply prevention of cruelty to animals or gross maltreatment to poor practices. Ideally, legislation should require all bird sellers to maintain a bird supplier list detailing name, address and phone number of supplier, dates of purchase, and bird types.

Guidelines and protocols

To ensure consistent standards and practices, the development of national pet store construction/fit out guidelines for commercial keeping and selling of birds based on a risk management approach is required. In addition, the development of national pet store operating guidelines including the typical signs of Chlamydiosis, action to be taken for bird care and public health protection for the species kept, the role of and appropriate care by veterinarians, and improving husbandry and disease control for species kept are also required. The development of a national pet store risk assessment inspection tool based on the construction/fit out and operating guidelines for officers to use to inspect and record risks is also required. This will enhance universal understanding across various agencies of the risks to be considering during a routine visit or in the event of an outbreak of human psittacosis. A protocol is required for environmental health and public health practitioners on where and how to sample, store and transport environmental psittacosis samples (not bird samples) to meet diagnostic testing requirements in relation to human psittacosis cases. At the local level, Local Government Authorities need to implement protocols to ensure pet stores are a type of premises requiring development consent and building approval and ensure that all pet store applications are assessed for identifying potential public health risks with the construction fit out and operation of and practices within pet stores.

Training

Training and some form of accreditation of pet shop owners and staff on the risk of psittacosis to themselves, their staff and the public is a fundamental requirement. It was evident during this investigation that there was limited knowledge across the various agencies on psittacosis disease, the potential risks to human health, and best practices to reduce risk in pet stores selling caged birds. Training and information for Environmental Health Officers as well as other agencies such as WorkCover and RSPCA officers is required to ensure a consistent understanding of roles and responsibilities, legislative responsibility, human health risks, risk assessment and mitigation measures required to prevent further cases of human of psittacosis.

Interagency collaboration and research

During this investigation it was evident that interagency collaboration is paramount. A NSW or National psittacosis public health task force is recommended to discuss further research into the practices of other pet stores who keep and sell caged birds to determine the magnitude of public health risk, to determine responsible agencies, to develop appropriate guidelines and protocols, and to advocate changes to relevant legislation and implement practices to prevent human psittacosis cases in the future.

Conclusion

Our epidemiological and laboratory investigation implicated the pet store as the likely source for this cluster of human psittacosis cases. The environmental health risk assessment identified a number of hazards. The potential severity of psittacosis demands that the prevalence of risk practices in pet stores is more fully investigated and the roles of agencies in responding is more clearly defined. It is essential that appropriate measures are implemented to reduce the risk of outbreaks associated with pet stores in the future.

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Education and Training in Environmental Health Services Evaluation

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A multi-functional educational and training module in Environmental Health Services Evaluation has recently been developed to build environmental health management evaluation capacity in Australia. Three institutions involved in the delivery of environmental health educational programs worked together with other key stakeholders to produce a module in Environmental Health Services Evaluation. A consultative approach was adopted to identify key content areas, and provide expert feedback on the content and format of delivery. The product, 12 connected modular sessions in Environmental Health Services Evaluation, is available for use, in a range of delivery-modes, by institutions involved in the education of environmental health practitioners (EHPs). This paper reports on the development of this module and its potential for improving evaluation and hence practice and outcomes in environmental health.

Key words: *Environmental Health Education; Environmental Health Services; Evaluation; Workforce Training*

The Environmental Health Services Evaluation initiative is in response to three priority areas identified by a joint committee involving the Department of Health and Ageing, the Australian Network Association of Public Health Institutions (ANAPHI) and the National Public Health Partnership (NPHP). The priorities included environmental health, program evaluation and workforce training. At the time of development, the linkages between environmental health, program evaluation and workforce training were seen to be weak in Australia. Evaluations of environmental health services were infrequently performed[1] posing limitations on policy development and environmental health service delivery. Similar needs identified internationally resulted in the development by WHO of guidelines for evaluation of environmental health services (Drew, van Duivenboden & Bonnefoy 2000), which was subsequently used in the development of the module which is the subject of this article.

Course coordinators from two universities in Victoria (Swinburne University of Technology and La Trobe University - Bendigo) involved in the delivery of accredited Australian Institute of Environment Health (AIEH) programs identified the need to strengthen the evaluation components in the context of environmental health within their own courses, with the potential for this to be applied more widely to other educational providers in this area. This was in response to the need to enhance environmental health capacity, particularly in the area of evidence based practice, outlined in Australia's National Environmental Health Strategy (Department of Health and Aged Care 1999) and reflected in the AIEH environmental health course accreditation policy (Australian Institute of Environmental Health 2005).

They collaborated with an educator and an experienced health program evaluator at The University of Melbourne to address this local and potentially wider national need. An Internet search of the curricula of eight

AIEH accredited courses, suggested a need to build evaluation into the curricula and subsequently to enhance the competency of environmental health practitioners (EHPs) in the field of evaluation.

In 2002, the Public Health and Education Program (PHERP), an Australian Government initiative with the aim of strengthening the capacity of the public health workforce across the country, offered funding for innovations that met its aims of workforce capacity building in the priority areas identified. One of the principles underpinning PHERP funding, was collaborative innovations. In line with this principle, a proposal was put together to develop and implement a module covering the subject area: *Environmental health services evaluation*. This was to be done in collaboration with The University of Melbourne, Swinburne University of Technology, La Trobe University - Bendigo, the Department of Human Services and the Australian Institute of Environmental Health (Victorian Branch). An EHP with expertise in the issues facing Aboriginal and Torres Strait communities joined the collaboration to provide assistance to the group to ensure the materials to be developed were also relevant to the workforce addressing environmental health needs in these communities.

PHERP funding was obtained to develop a teaching module that could be useful to distance and face-to-face modes of delivery, and was able to function as a resource for an accredited undergraduate and postgraduate subject and a standalone workforce training course to develop evaluation in the environmental health workforce. A further aim of the proposal was to promote environmental health outcomes through improved questioning and examination of environmental health services as espoused in the Australian Charter for Environmental Health, a key driver of the National Environmental Health Strategy:

> *Improving the delivery of environmental health services, encouraging innovation, and careful examination of how environmental health services are provided - including the relative costs and benefits of each alternative - are important considerations for optimal environmental health outcomes* (Department of Health and Aged Care 1999 p. 9).

There is an increasing emphasis on evidence-informed practice in environmental health. Evaluation is one of the tools used to improve service delivery, gain a better understanding of important program and service operants, and promote innovation.

Framework for the Development of the Module

In developing the module, particular emphasis was placed on the process elements as well as on the outcome. Process elements of successful program planning include:

- clarifying the needs of the stakeholders;
- ensuring meaningful participatory decision-making;
- developing flexible, acceptable and practicable programs for specific groups;
- consensus about desired process and outcomes;
- reflective practice to ensure that needs have been met (Talbot & Verrinder 2005)

The initiative involved five key steps:

- setting up a committee of representatives from institutions interested in incorporating the module in their education and training programs, or skilling their workforce;
- consulting a range of EHPs to find out what topics and case studies they would like to see in the course;
- identifying case studies to be used in the module;

- developing a module with CD Rom based trainer notes and resources;
- establishing an electronic trainer forum for trainers to share materials, ask advice and provide feedback on the course;
- involving experts across Australia to comment and provide feedback on drafts of the modules during development; and
- disseminating, delivering, and establishing ongoing quality improvement of the module.

Each of these key steps is described more fully in the following sections of the paper.

The steering committee

To ensure that the needs of the stakeholders would be met, a steering committee was set up to include the manager of the Environmental Health Unit, Department of the Human Services, Victoria (DHS), the Victorian State President of the Australian Institute of Environmental Health - Victorian Branch, and three educators from each of the universities: The University of Melbourne, Swinburne University of Technology and La Trobe University-Bendigo. A representative of the Environment Protection Authority, Victoria, and an environmental health practitioner (EHP) with expertise in Aboriginal environmental health were available to the committee for advice.

Seven steering committee meetings were convened over the duration of the project. Many of these steering committees ran back-to-back with 'sub-committee' working group meetings of the three educators to discuss pedagogical issues. The wider steering committee would later meet to discuss issues concerning the progress and promotion of the course. Functions of the steering committee included:

- clarifying terms of reference and key milestones of the committee;
- identifying key experts within the collaborating organisations and elsewhere;
- identifying performance indicators for the development and implementation of the module;
- confirming core content and areas of emphasis for the module;
- identifying essential elements of and uses for the electronic trainer forum;
- providing expert feedback on course materials, the overall approach of the initiative; and
- providing resources and case studies to be incorporated into the module.

Consultation to identify priority areas and case study preferences

A structured mailed questionnaire, face-to-face interviews and a telephone interview of EHPs were performed to ask them what they would like to see included in such a course and to gain a greater understanding of the range of environmental health services in the State Government and Environmental Health Authority settings.

The structured questionnaire was sent to all Environmental Health Officers (EHOs) in Victoria and Western Australia (WA) and a number of EHPs, for example, state managers, and EHPs involved in Aboriginal environmental health. EHOs in Victoria and WA were chosen because of the geographic and demographic disparities between the two. This sample provided information about the wide range of issues and service areas undertaken by EHOs across Australia.

The face-to-face or telephone interviews of EHPs took place with key representatives of the Environmental Health Branch of the Victorian Department of Human Services, the Victorian Environment Protection Authority, the Australian Institute of Environmental Health, and an EHP with expertise in Indigenous environmental health issues at the national level.

These processes together helped identify priority content areas for evaluation. The processes also informed the development of case studies to be used as learning tools in the development of the course.

Developing the content

The themes that emerged from the respondents include the measurement of outcomes, data collection methods, basic evaluation theory, the development of performance indicators, strategies to promote 'change' in the political environment (evaluation utilisation); reasons why EHPs should evaluate; program logic, efficiency of resource use, and identifying best practice. The evaluation of risk communication activities was also raised, as was the evaluation of program outcomes, particularly for programs addressing air and soil pollution, waste-management, industrial regulation and immunisation.

The committee decided that generic data collection methods, for example, how to develop a survey or how to run a focus group, would only be covered in an introductory manner in the module, due to the many generic courses on data collection methods available. However, the importance of choosing an appropriate design, particularly when making inferences of causation, was considered an important aspect to include in the module particularly in relation to the evaluation of program or service delivery.

Development of case studies

An important aspect of the module development was to include the use of case studies as a means to develop 'authentic activities' which simulated actual situations (Conrad & Donaldson 2004). Using these types of activities is important in 'order to connect the learning gained from everyday life to the course in order to create a deeper sense of meaning for the participants and validated them as people who possess knowledge and who can apply what they know in other contexts' (Palloff & Pratt 1999 p. 116). To be effective, the activity must have value outside the learning setting and should build skills that can be used beyond the life of the course enhancing student's problem-solving power (Conrad & Donaldson 2004).

Case studies which were representative of environmental health practice were actively sought. Many of the respondents in both WA and Victoria stated food safety and waste-management or waste water management as areas they would like to see addressed in the module. Most other case study areas were similarly reported across both states except for the areas of Indigenous environmental health, and building inspections, which were raised by Western Australian EHOs. Risk management was identified by EHPs across both states, more so for WA. This is one area not covered in detail in the module as it was considered that many environmental health activities were in fact 'risk management', therefore evaluation activities would be inherently considered. The steering committee discussed each of the potential case studies that could be used for each of the areas. Hypothetical scenarios were also developed and incorporated in the module to illustrate key evaluation concepts where case studies had not been identified.

The module

Consensus among steering committee members was reached about the content of the 12 sessions (see Table 1). The first nine sessions cover key evaluation concepts with a range of case studies covering those areas raised during the survey. It was decided that three key case study areas would be used as whole sessions each to apply the learning of the previous sessions on a thematic level. These study areas included Aboriginal health, food safety and air pollution. These three areas were chosen because they would demonstrate particular evaluation concepts and relate to particular EHP roles, for example, remote EHOs (Indigenous health), urban EHOs (food safety) and EHPs working in State-based environmental protection authorities (air pollution). Aboriginal Environmental Health was also a priority area decided at the funding stage, and required a session devoted to the issues of evaluating environmental health programs or service delivery.

Table 1: Titles of Sessions

Session 1:	Environmental Health Services Evaluation - What is it and why do it?
Session 2:	What aspect/s of an Environmental Health service can be evaluated?
Session 3:	Planning the Evaluation - Choosing from the rich and varied evaluation menu.
Session 4:	Defining the Environmental Health Program for Evaluation
Session 5:	Data collection approaches, methods and sources useful for the evaluation of environmental health services
Session 6:	The Evaluation of Environmental Health Program Processes
Session 7:	The Evaluation of Environmental Health Program Outcomes
Session 8:	Performance Indicators
Session 9:	Economic Evaluation of Environmental Health Services
Session 10:	Evaluation in Practice: Aboriginal Environmental Health
Session 11:	Evaluation in Practice: Food Safety
Session 12:	Air Pollution: Evaluating Strategies Designed to Address Air Pollution

Development and evaluation of the module

The module was drafted primarily by one author, the project coordinator. Health economists from The University of Melbourne wrote the economic evaluation session. Steering committee members and other interested EHPs across Australia provided feedback on each session. The sessions were sent out to specific people with expertise or interest in the topic.

The development of the CD Rom for Distance Education contains two versions - the student version and the tutor version. The tutor notes include the answers to the learning activities interspersed throughout the sessions. The student version has links to the answers that display once the students have attempted the activity. The steering committee agreed that by incorporating the tutor's notes in the module, it would be user-friendly for the tutor. This would avoid the tutor moving between two documents - the student notes, and their own. The students' version allows each student to obtain the 'answers' to the learning activities once they have attempted each activity. This approach was adopted so that students were provided with immediate feedback and opportunities for cross-checking to enhance the learning experience (Butler & Winne 1995). Readings are provided in CD Rom or hard copy depending on the preferred format of the subject coordinator. For copyright purposes, each institution using the module is required to obtain a copy of the relevant readings. A list of the titles of the references used in the module with the 'readings' for students is provided.

A tutor's electronic forum has been set up to allow those using the module to provide suggestions for improvement, suggest other case studies or readings as they come to their notice, provide tips for assessment or delivery, and find out about future updated versions of the module. It is expected that the forum will be useful with wider use of the module. The forum is part of the reflective practice outlined earlier which is essential in program planning and evaluation.

The module is available for use by all teaching institutions involved in teaching EHPs in Australia. It is now in its second cycle of use in face-to-face mode in an undergraduate degree at Swinburne University of Technology. The subject coordinator (steering committee member), has been providing feedback during and following its delivery. Comments on its first trial in 2005 included:

> *Overall the program is great, and the breath of topics covered is terrific. I think some of the students are finding that there is a lot to take in with the readings etc, particularly for EH students as the science subjects do not have the same approach, but this is a good thing I think!* (Course deliverer).

The subject evaluation results, undertaken as part of university reporting requirements, have indicated that the subject has been favorably received. Feedback has indicated that students enjoyed developing a broader understanding of evaluation processes and the role of evaluation in enhancing environmental health practice.

A short-course was also developed that incorporated key elements of the module. It has been conducted in Queensland twice, in collaboration with the Queensland University of Technology, first at the institution, and second as an AIEH Queensland State Conference 2-day workshop.

The module has also been used as part of a subject in the Masters in Environmental Health at Queensland University of Technology, and in second semester 2006 has been offered for the first time in distance mode to Masters of Public Health and Masters of Environment students through The University of Melbourne.

Aims and Learning Outcomes

In program planning and evaluation the best outcome is to achieve the goal which in this case is an environmental health workforce competent in evaluation. At this stage, we do not know if we have reached this goal, but one of the project objectives towards achieving this was to develop an innovative module in a collaborative way that was accessible, flexible and practicable.

As the program is utilised by teaching institutions, it is expected that practitioners skilled in evaluation, will strengthen the relevance, effectiveness and efficiency of their practice. EHPs will be more competent in the planning and implementation of evaluations of environmental health services. The knowledge-base with regard to the content, process, organisation, efficiency and effectiveness of environmental health services will be enhanced. Policy making with regard to the operation of environmental health services will be better informed, and finally, environmental health outcomes will be improved. The feedback loop of theory informing practice and practice informing theory will continue.

Program planning and evaluation is a dynamic process and this module will continue to change to meet the needs of the stakeholders. Case studies will continue to be collected and incorporated into the module, and provided as additional resources to ensure that there is a variety of current and relevant case studies available in the longer term. Different case studies will suit different audiences, hence the need to maintain a bank of relevant case studies. Students of the short courses in particular will have the opportunity to apply their learning to their own workplace based activities.

Conclusion

The education and training module has been developed as a response to the growing recognition of the need to strengthen evidence informed practice in environmental health activities. It is anticipated that the consultative approach adopted in the module development, the flexible delivery of the program and the ongoing mechanisms for the evaluation and improvement of the module will ensure the module is a not only a valuable learning tool for the environmental health workforce, but assist in informing policy and decision making in environmental health service delivery.

Endnotes

1. Anecdotal evidence that is supported by statements in the National Environmental Health Strategy (1999).

Acknowledgments

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Note

The distance delivery of the module will be administered by The University of Melbourne. Institutions involved in environmental health education and training will be able to access the course via Distance Education as a subject of The University of Melbourne, or a subject of the student based university. The module will be made available to Australian institutions to incorporate into their teaching programs for face-to-face teaching. Those already within the workforce will be able to access the course via distance education through The University of Melbourne, face-to face as a standalone semester-long or short course, or as one of its postgraduate programs.

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Public Health Practice in Australia: The Organised Effort

Vivian Lin, James Smith and Sally Fawkes

Allen & Unwin, 2007, 512 pp. ISBN 978 1 860508 875 4, $79.95

As there is a vast array of introductory or general books available on public health, one may ask 'why do we need another book on public health?' The authors of this new book answer this question by saying 'while others have written about and debated the concept of public health, and how to think about public health, we give emphasis to the '"doing" of public health' (p. xv). The authors also indicate that the title, *Public Health Practice in Australia: The Organised Effort*, was chosen 'to focus on what public health practitioners do, and to highlight some common threads that underlie all the seemingly disparate activities, ideas and entities included in the notion of public health' (p. xv). Therefore, the aim of the book is to 'address the range of methods used in public health practice, their conceptual framework, and the system components that underpin their delivery' (p. xvii). The book consists of 19 chapters that are organised into five parts, each covering a different dimension of the broad and organised effort of public health practice.

Part 1 provides an introduction to the basic elements of the field of public health. This includes defining what public health is, discussing the historical development of public health, and introducing the current health care system in Australia and the role of public health within this system.

Part 2 discusses key concepts and frameworks through examining the basic 'toolkit' used in public health practice. This includes the distribution and determinants of health, public health interventions, and health systems and policy.

Part 3 then describes the current public health infrastructure. Topics discussed are public health service delivery and policy, public health legislation, public health intelligence and information sources, and the human and financial resources necessary for the delivery of public health programs.

Part 4 goes on to discuss public health interventions and actions. The key topics covered are surveillance and disease control, health protection and environmental health, preventive services, health promotion, and health maintenance and improvement for vulnerable populations.

The final Part then discusses a range of current and future public health challenges that are faced due to emerging issues and our responses to these. This part focuses on the contemporary decision points for public health action and policy, and includes a discussion of public health governance, future issues or challenges for public health in Australia, and the book concludes with a short note on ethical public health practice.

As can be seen from the topics discussed above, this book covers the vast scope of public health practice. On reading, it is clear that the authors have approached this task by drawing on their strengths in public health policy, health systems development and evaluation, environmental health, health promotion, and epidemiology. As such, they provide a comprehensive treatment of the material and bring practical knowledge and experience to the topics. Each chapter is highly illustrated through the inclusion of figures, diagrams and textboxes that emphasise key points or provide case studies that illustrate the relevance of the accompanying material. The book is impressive in the

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completeness, clarity and consistency of the material covered, and for the way in which many of the theoretical issues are related to current practice.

Overall, the authors have achieved their aim and the outcome is an extremely useful and valuable reference for both students and practitioners alike. I am sure that many practitioners who read this book will immediately identify with the way in which the topics are presented, and will be impressed that this one book has been able to pull all of the pieces of our complex public health system together in such a neat package. As such, I highly recommend this book for all students and practitioners who are interested in effectively practicing public health in Australia.

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Calculated Risks: The Toxicity and Human Health Risks of Chemicals in our Environment, 2nd edition

Joseph V. Rodricks

Cambridge University Press, 2007, 339 pp. ISBN-10 0-521-78308-9

The second edition of *Calculated Risks: The Toxicity and Human Health Risks of Chemicals in our Environment* is a fully revised and updated version of the first edition that is highly regarded and which had won an 'Honorable Mentions' award from the American Medical Writers Association. Since the release of the first edition in 1992, the role of risk assessment in guiding decisions by both government and the public alike, has gained widespread prominence and 'has come to be seen as a most powerful tool for evaluating and putting into useful form the complex, diverse, often inconsistent, and always incomplete scientific information and knowledge we have been able to accumulate about the health hazards and risks all chemicals pose if exposures become excessive' (p. xiii). Therefore, the purpose of this second edition of is to provide 'a broader and deeper look at risk assessment as it continues to evolve as a scientific enterprise, and in its role as the bridge between basic and applied research and the many forms of decision-making aimed at risk reduction' (p. xiii).

The book is essentially in two parts: the first half provides a detailed description of basic chemistry and toxicology and their role in risk assessment. The second half then provides a detailed overview of human health risk assessment principles, applications, and future developments. The sequencing of the information provided is extremely good as each chapter nicely builds on the previous one to take the reader on a detailed but easily understandable journey from basic principles to their application and beyond.

The first chapter provides an excellent introduction to chemicals and human exposure to these. The next few chapters then delve into fundamental toxicological principles such as toxicodynamics, toxicokenetics, dose-response assessment, and the organ systems impacted by chemical exposure. These topics are seen by many practitioners to be too complex and a little difficult to understand, but the way in which the material is presented really demystifies these topics, as can be seen by the chapter titles of 'From exposure to dose', 'From dose to toxic response', and 'Toxic agents and their targets'. The next two chapters then focus on carcinogens and how they are identified.

Chapters 7 to 10 then deal with human health risk assessment, particularly associated with chemical exposures. The basic concepts and principles are briefly described in chapter 7 and then these are illustrated very nicely in the next chapter. This chapter describes a step-wise approach to undertaking human health risk assessment and discusses assessment approaches for substances that act through threshold or non-threshold (i.e. carcinogenic) mechanisms. The next two chapters deal with new approaches and new issues being addressed by risk assessment, and the ever increasing involvement of risk assessment in litigation.

The book concludes by discussing risk management and some of the future issues for risk assessment and risk management. The chapter on risk management provides an excellent discussion on basic considerations for risk managers such as 'the notion of safety' and 'how safe is it', and aspects of risk perception that influence the communication of risk-based decisions. This chapter also provides nice illustrations of how the risks from a number of exposure scenarios, for example, pharmaceuticals, pesticides, drinking water, industrial chemicals, and air pollutants, have been managed.

Overall, this book does an excellent job in presenting complex material in a very readable way. Due to the topics covered, I expect that it will be most appropriate for advanced students or experienced practitioners, however, the way in which it covers the material in such a clear and concise way also makes it a useful resource for all environmental health practitioners. I am sure that this, the second edition of *Calculated Risks*, will become a key reference for anyone involved in human health risk assessment and I will not be surprised if it receives a few more literary awards.

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