Author/s:
Beggs, PJ;Katelaris, CH;Medek, D;Johnston, FH;Burton, PK;Campbell, B;Jaggard, AK;Vicendese, D;Bowman, DMJS;Godwin, I;Huete, AR;Erbas, B;Green, BJ;Newnham, RM;Newbigin, E;Haberle, SG;Davies, JM

Title:
Differences in grass pollen allergen exposure across Australia

Date:
2015-02-01

Citation:
Beggs, P. J., Katelaris, C. H., Medek, D., Johnston, F. H., Burton, P. K., Campbell, B., Jaggard, A. K., Vicendese, D., Bowman, D. M. J. S., Godwin, I., Huete, A. R., Erbas, B., Green, B. J., Newnham, R. M., Newbigin, E., Haberle, S. G. & Davies, J. M. (2015). Differences in grass pollen allergen exposure across Australia. Australian and New Zealand Journal of Public Health, 39 (1), pp.51-55. https://doi.org/10.1111/1753-6405.12325.

Persistent Link:
https://hdl.handle.net/11343/263380

Differences in grass pollen allergen exposure across Australia

Paul J. Beggs,[1] Constance H. Katelaris,[2] Danielle Medek,[3] Fay H. Johnston,[4] Pamela K. Burton,[5] Bradley Campbell,[6] Alison K. Jaggard,[1] Don Vicendese,[7] David M.J.S. Bowman,[8] Ian Godwin,[6] Alfredo R. Huete,[9] Bircan Erbas,[7] Brett J. Green,[10] Rewi M. Newnham,[11] Ed Newbigin,[12] Simon G. Haberle,[13] Janet M. Davies[14]

Abstract

Objective: Allergic rhinitis and allergic asthma are important chronic diseases posing serious public health issues in Australia with associated medical, economic, and societal burdens. Pollen are significant sources of clinically relevant outdoor aeroallergens, recognised as both a major trigger for, and cause of, allergic respiratory diseases. This study aimed to provide a national, and indeed international, perspective on the state of Australian pollen data using a large representative sample.

Methods: Atmospheric grass pollen concentration is examined over a number of years within the period 1995 to 2013 for Brisbane, Canberra, Darwin, Hobart, Melbourne, and Sydney, including determination of the 'clinical' grass pollen season and grass pollen peak.

Results: The results of this study describe, for the first time, a striking spatial and temporal variability in grass pollen seasons in Australia, with important implications for clinicians and public health professionals, and the Australian grass pollen-allergic community.

Conclusions: These results demonstrate that static pollen calendars are of limited utility and in some cases misleading. This study also highlights significant deficiencies and limitations in the existing Australian pollen monitoring and data.

Implications: Establishment of an Australian national pollen monitoring network would help facilitate advances in the clinical and public health management of the millions of Australians with asthma and allergic rhinitis.

Key words: pollen, allergen, season, allergic rhinitis, allergic asthma

Allergic rhinitis is a medically and economically important chronic disease that affects 500 million people worldwide.[1] In a study of the geographical distribution of allergic rhinitis in adults aged 20–44 years living in 35 centres in 15 countries, the prevalence of allergic rhinitis in Australia (Melbourne) was the highest, at 31.8%.[2] Australia is also prominent with its prevalence of asthma being amongst the highest in the world. For example, Phase Three of the International Study of Asthma and Allergies in Childhood (ISAAC) found the prevalence of current wheeze and severe asthma in children in Australia to be >20% and >7.5% respectively.[3] The coexistence of asthma and allergic rhinitis is frequent, and it has been demonstrated that allergic rhinitis usually precedes asthma, and that allergic rhinitis is a risk factor for asthma.[4]

The direct and indirect costs of allergic disease have been estimated at $7.8 billion annually for Australia alone, with $1.2 billion (15%) of this being the direct health system expenditure.[5] The main treatment of seasonal allergic rhinitis is chronic pharmacotherapy including intranasal corticosteroid sprays and non-sedating anti-histamine drugs. Unlike medications for asthma management and prevention, most pharmacotherapy for seasonal allergic rhinitis is not subsidised by the Australian Pharmaceutical Benefits Scheme; typically the patient bears the considerable cost of treatment for this chronic disease over many years. Alarmingly, pharmacy wholesale purchases for oral anti-histamines and nasal steroids doubled between 2001 and 2010 to $226.8 million.[6]

1. Department of Environment and Geography, Macquarie University, New South Wales
2. Department of Medicine, Campbelltown Hospital and School of Medicine, University of Western Sydney, New South Wales
3. Harvard School of Public Health, Harvard University, Massachusetts, US
4. Menzies Research Institute Tasmania, University of Tasmania
5. Department of Medicine, Campbelltown Hospital, New South Wales
6. School of Agriculture and Food Science, The University of Queensland
7. School of Public Health and Human Biosciences, La Trobe University, Victoria
8. School of Plant Science, University of Tasmania
9. Faculty of Science, University of Technology, Sydney, New South Wales
10. Allergy and Clinical Immunology Branch, Centers for Disease Control and Prevention, West Virginia, US
11. School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand
12. School of Botany, The University of Melbourne, Victoria
13. Department of Archaeology and Natural History, The Australian National University, Australian Capital Territory
14. School of Medicine, The University of Queensland
Correspondence to: Associate Professor Paul J. Beggs, Department of Environment and Geography, Faculty of Science, Macquarie University, Sydney, NSW 2109; e-mail: paul.beggs@mq.edu.au
Submitted: June 2014; Revision requested: August 2014; Accepted: October 2014
The authors have stated they have no conflict of interest.

Aust NZ J Public Health. 2015; 39:51-55; doi: 10.1111/1753-6405.12325

Grass pollen are significant sources of clinically important outdoor aeroallergens and recognised as a major trigger for allergic rhinitis.[7-10] Allergen challenge studies have demonstrated the causal link between grass pollen allergens and allergic rhinitis in a number of studies.[11-12] Environmental exposure to pollen can directly affect patient symptoms of allergic respiratory disease including allergic rhinitis and asthma, and indeed the initial development of these diseases.[13] For example, increases in the atmospheric concentration of grass pollen have been associated with significant increases in hospital emergency department visits and admissions for asthma.[14-15] Grass pollen and associated cytoplasmic fragments are now widely considered as the major causative allergen in Australian thunderstorm asthma epidemics.[16-19]

Establishment of long-term airborne pollen count data across several nations has been an integral aid towards measuring exposure of populations to aeroallergens.[20-21] Improved knowledge of local pollen aerobiology assists people in self-management of both allergic rhinitis and allergic asthma symptoms, thereby reducing the health and financial burden of these diseases. Airborne pollen data has the additional potential to be used in a predictive manner by the generation of short-term pollen forecasting.[22-23]

To date, there has been no national compilation of airborne pollen concentration data for Australia. However, regional variability in pollen seasons might be anticipated across the geographically and climatically diverse continent of Australia. Pollen monitoring has been performed in a small number of sites within the coastal state capital cities where most of the Australian population reside. With support from the Australian Government (see Acknowledgements for details), this study sought to integrate all existing available Australian capital city airborne pollen datasets into a national collection and provide, for the first time, a descriptive snapshot of the current status of pollen exposure across Australia, with implications for clinical management of allergic respiratory diseases. The initial report from this study, by Haberle et al.,[24] focused on the macroecology and biogeography of diverse pollen types. Here we report an analysis and synthesis of pollen count data from urban centres of Australia for grasses, the major clinically important outdoor aeroallergen source, with consideration of the public health implications relating to the need to better facilitate management of grass pollen allergen exposure. There are other important aeroallergens (other pollen, mould spores, etc), but our analysis here is just on grass pollen, not these other aeroallergens.

Methods

Daily mean airborne grass (Poaceae) pollen concentration data was analysed for six major urban centres in Australia: Brisbane, Canberra, Darwin, Hobart, Melbourne and Sydney. The other two state capital cities, Adelaide and Perth, were not included because limitations in the available data or documentation prevented determination of grass pollen season using the methods detailed below.

The grass pollen season for each year of every location was determined using the 90% and 98% methods.[25-27] The 90% method defines the pollen season as the period starting when the sum of daily mean pollen concentrations reaches 5% of the annual total sum and ending when the sum reaches 95% of the annual total sum; i.e. the interval with 90% of the annual pollen amount.

Similarly, the 98% method defines the pollen season as the period starting when the sum of daily mean pollen concentrations reaches 1% of the annual total sum and ending when the sum reaches 99% of the annual total sum; i.e. the interval with 98% of the annual pollen amount.

Pollen season is defined in these ways in order to disregard extremely low, clinically irrelevant, pollen counts leading up to the start and following the end of the clinically important pollen season. The peak grass pollen date for each year and every location was determined as the highest 7-day moving average grass pollen density, similar to that used by Khwarahm et al.[28] The peak pollen date is important because it can be clinically significant, as discussed by Ribeiro et al.[29] These methods of defining the start and end and peak of the pollen season can only be applied retrospectively, after all the data has been collected for the entire year.

The grass pollen analyses have been expressed across fiscal years, from July to June of the following year, as this illustrates the seasonality patterns more clearly in most cases. The years analysed for each location were: Brisbane (1995-1996 to 1998-1999); Canberra (2007-2008 to 2009-2010); Darwin (2002-2003 to 2004-2005); Hobart (2007-2008 to 2010-2011); Melbourne (2009-2010 to 2011-2012); and Sydney (2008-2009 to 2012-2013).

Results

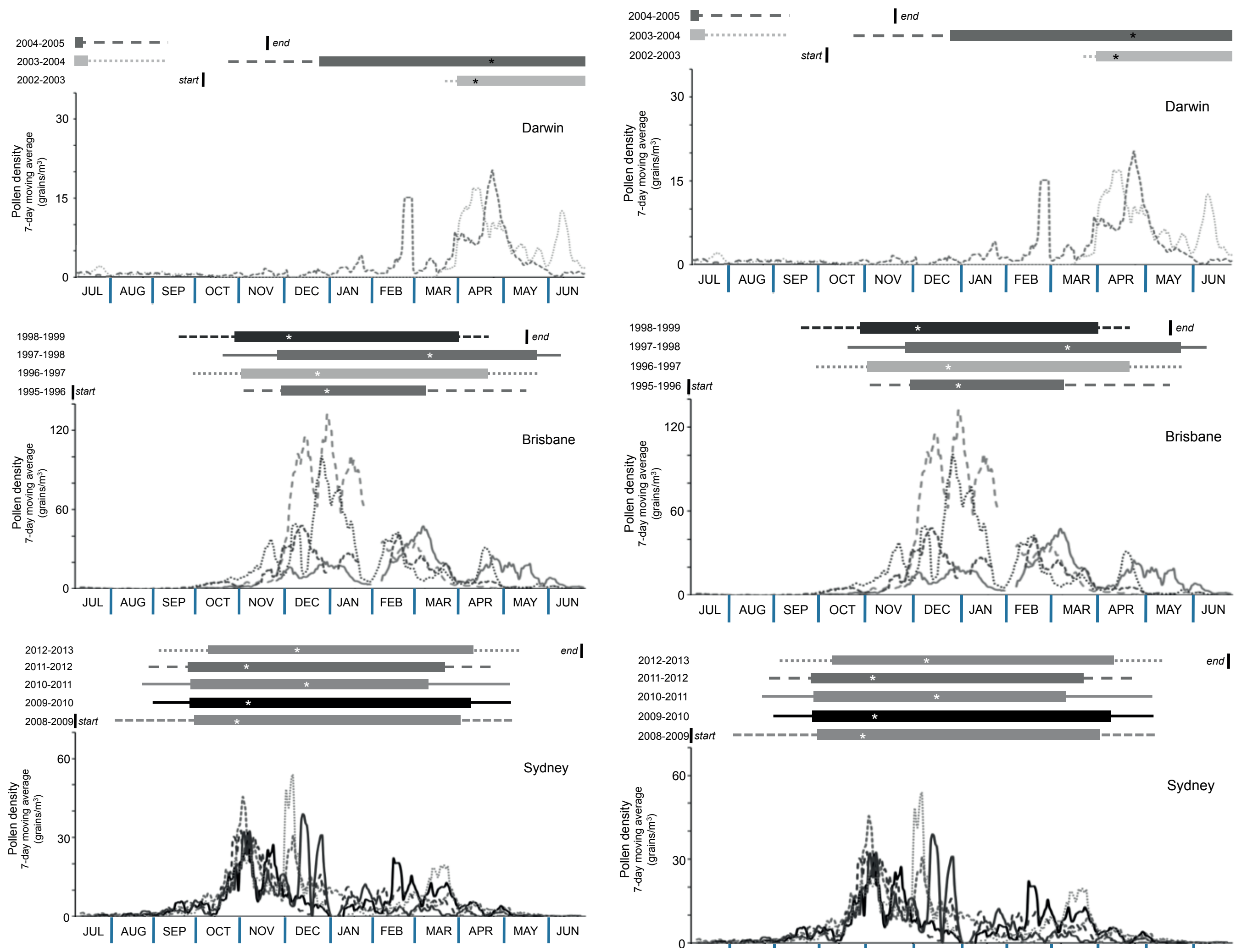
Results for Brisbane, Canberra, Darwin, Hobart, Melbourne, and Sydney are presented in Figure 1. The curves for each year and location show the short-term temporal variation in grass pollen density. There are considerable differences in this variation not only from one location to another but also from year to year at the same location.

Similarly, the peak grass pollen date differs from one location to another but also from year to year at the same location (shown in the curves and indicated by the asterisk in the corresponding grey shade and/or line type box above the curves in Figure 1). For example, three of the five Sydney years have their peak grass pollen date at the end of October/start of November; the other two years have their peak grass pollen date more than a month later in December. For Brisbane, the grass pollen peak date variability is even greater, with three of the four years peaking around December, and the fourth year peaking 2-3 months later in March.

Similar to the short-term temporal variation in grass pollen density and peak grass pollen date, considerable differences in grass pollen season timing and length are observed between locations and from year to year at the same location (Figure 1). For example, over the four years presented, Brisbane's grass pollen season starts anywhere from mid-September to late November (taking both pollen season expression methods into account), whereas Sydney's starts anywhere from the end of July through to early October (taking both pollen season expression methods into account). On the basis of the 90% pollen season definition method, Brisbane's start date varies by more than a month and end date varies by almost three months, for just the four years that are considered here.

The other striking result is the contrasting grass pollen season between Darwin and the other five sites. This suggests latitudinal variation in grass pollen seasons, with Darwin peaking around April based on the data available from two years, and all the other (more southerly) sites preceding this, by several months in most cases.

Figure 1: Atmospheric grass pollen density and seasons for six cities in eastern and northern Australia. The cities are arranged by latitude from north at the top left to south at the bottom right. Grass pollen density is shown as a 7-day moving average across the fiscal year. Grass pollen season is depicted by the combination of thin horizontal line (98% of the annual grass pollen falling in this range) and a thick horizontal box (90% of the grass pollen falling in this time) for each year. Peak grass pollen date each year is indicated by the asterisk in the box, with the corresponding curve in the same shade below. The vertical bars labelled "start" and "end" in the upper part of each panel indicate the start and end of pollen sampling for the corresponding location. Note change in y-axis scale for Darwin and Brisbane.



Conclusions

Examination of the available grass pollen data for Australia presented here highlights the great variability observed in grass pollen seasons across regions and between years. These results demonstrate that static grass pollen calendars, which typically indicate presence or absence of grass pollen on a monthly basis, are of limited utility and in some cases misleading to clinicians, public health professionals and respiratory allergy sufferers in general. Furthermore, static grass pollen calendars are of no value as indicators of peak grass pollen periods. Again, the results of this study clearly demonstrate peaks in airborne grass pollen can occur at almost any stage of the grass pollen season, near the start, around the middle, or near the end. Notably, although only the highest peak is identified in this study, some locations and/or years will experience multiple peaks, possibly due to variations in flowering intervals of different grass species, as observed elsewhere.[30]

While detailed analysis of the causes of the temporal and spatial variability in grass pollen season revealed here was not the objective of this study, mention of the likely dominant factors is important. First and foremost, climate and weather will play a dominant role with respect to the spatial distribution of different grass species in Australia as well as the short-term and seasonal temporal variability of grass pollen production. The dominant grasses will vary across the many climate zones of Australia, with, for example, subtropical Brisbane dominated by subtropical Bahia grass (*Paspalum notatum*) and Bermuda grass (*Cynodon dactylon*), and temperate Sydney, Canberra, Melbourne, and Hobart dominated by the temperate Ryegrass (*Lolium perenne*).[8] Rainfall, temperature and other meteorological parameters will influence pollen season timing and duration as well as day to day variations in pollen concentration, as will synoptic and larger-scale climate fluctuations such as the El Niño Southern Oscillation. For example, the delayed and diminished 1997-1998 Brisbane grass pollen season corresponded with a 12-14 month El Niño that started early 1997, which was associated with below average rainfall in eastern subtropical Queensland.[31]

This study reports the most comprehensive and systematic analysis and synthesis of Australian grass pollen data conducted, and reveals insights into grass pollen exposure in Australia that were previously unknown. However, they also highlight significant deficiencies in data collection for this continent when compared to the extensive and comprehensive databases available in North America, where there are approximately 87 pollen and mould spore counting stations,[32] and Europe, where there are more than 600 pollen counting stations.[33] Furthermore, even for the limited number of Australian sites for which pollen data is available, operation of monitoring in most cases is not continuous. Monitoring in all cases is either unfunded or under-funded by short-term grants. Thus, even with the most recent of Australian pollen data, cities such as Darwin, for example, have just two years of data, ending in November 2004, and Canberra three years, ending in December 2009. Closer inspection of Figure 1 reveals a number of gaps within these limited periods of monitoring, such as for Brisbane (e.g. end January to start February 1995-1996) that experienced several periods of motorised spore trap breakdown.[34] These spatially and temporally restricted datasets highlight the poor resourcing of this important enterprise in Australia.

Finally, there are further limitations, and indeed inconsistencies, in the existing Australian pollen data. For example, there is no uniformity in the time that pollen monitors at different locations start and end their 24-hour or 7-day sampling period. Similarly, there is no uniformity in the placement of pollen traps in terms of their height above the ground, clearance from obstacles, etc. And there are no agreed standardised counting methods, despite all collection and count techniques conforming to recommended guidelines.[35]

Implications

The striking spatial and temporal variability in grass pollen seasons in Australia revealed in this study supports the pressing need for the establishment of a national pollen network. This would result in a systematic and standardised approach to mapping the pattern and nature of the seasons, providing data that is thus far lacking. Such information will lead to an improved understanding of the 'allergy season' for both medical practitioners and patients. Overseas experience and limited experience in Melbourne strongly suggests that patients with allergic rhinitis and allergic asthma feel a sense of empowerment and control over their symptoms when they have access to actual and forecast pollen levels, which may result in greater compliance with preventative medication use and long-term prevention of pollen allergen-induced emergency department visits and hospital admissions for respiratory disease.[36]

A further dimension to, and superimposed upon, the striking spatial and temporal variability in grass pollen season revealed herein, is the likely impacts of climate change on grass pollen seasons in Australia. Overwhelming evidence from the Northern Hemisphere now shows that the seasonality of flowering and pollination of many plants is changing.[37-39] A standardised and long-term national pollen network would enable observation of any long-term trend in atmospheric pollen concentrations, and provide a mechanism to project the impacts of climate change.[21,40]

For some states and/or territories, and indeed for some cites, there may be a requirement for more than a single pollen sampling site. Katelaris et al.[41] have examined the spatial variability in the total pollen count in Sydney, comparing three sites separated by a maximum of 30 km. Significant differences were found in the total sums of pollen at the three sites, as well as in the temporal variability of pollen from particular species. Similar results over comparable distances have been found in research on the spatial variation of airborne pollen over south-east France, a region that borders the coast, like many Australian cities.[42]

Other important considerations for an Australian national pollen monitoring network include its sustainability, including secure long-term funding, and its incorporation of new technologies, both now and into the future. One such technology is automated pollen classification and counting, which utilises recent improvements in computing and imaging hardware and software, and which makes this part of the process less labour-intensive.[43]

A national pollen monitoring network would provide the high-quality pollen data required for trials of new allergy treatments and therapies. Pollen exposure is an independent predictor of hospital admissions for respiratory disease and accurate measurements of ambient levels of pollen are critical to reduce pollen allergen-induced asthma emergency department visits and subsequent hospital admissions.[14-15] Another important need for high-quality pollen data is the requirement to include pollen as an important covariate in studies of the relationship between respiratory disease and air pollution (e.g. Jalaludin et al.[44]).

Patients in a small number of Australian cities are currently benefiting from ongoing pollen monitoring, reporting, and indeed forecasting, with Melbourne being perhaps the best served at present (see http://www.melbournepollen.com.au/). In conclusion, significant advances in the clinical management and self care of the millions of Australians with asthma and allergic rhinitis could be made through the establishment of an Australian national pollen monitoring network. Knowledge and management of pollen allergen exposure are likely to become increasingly important public health considerations to minimise the impact of these common chronic conditions.

Acknowledgements

Funding support for the Working Group came from the Australian Centre for Ecological Analysis and Synthesis (ACEAS), Terrestrial Ecosystem Research Network (TERN), which is supported by the Australian Government through the National Collaborative Research Infrastructure Strategy and the Super Science Initiative. MSD provided additional independent untied co-sponsorship for the Working Group. The authors wish to thank the staff of ACEAS, TERN for assistance in organising Workshops 1 and 2 of the Working Group "Understanding Australian aerobiology to monitor environmental change and human allergenic exposure", North Stradbroke Island, Australia (11-15 March and 4-8 November 2013 respectively). Alison Jaggard has been assisted by the New South Wales Government through its Environmental Trust (project reference number 2011/RD/0049). The findings and the conclusions in this report are those of the authors and do not necessarily represent the views of the US National Institute for Occupational Safety and Health. The authors wish to thank Associate Professor Jeroen Buters (Germany), Associate Professor Frank Murray (Australia), and Dr Michel Thibaudon (France) for their contributions to this research. Finally, we also thank two anonymous reviewers of the submitted manuscript who provided positive, thoughtful, and constructive comments on it.

References

1. Pawankar R, Canonica GW, Holgate ST, Lockey RF, editors. *White Book on Allergy*. Milwaukee: World Allergy Organization (WAO); 2011.
2. Bousquet PJ, Leynaert B, Neukirch F, Sunyer J, Janson CM, Anto J, et al. Geographical distribution of atopic rhinitis in the European Community Respiratory Health Survey I. *Allergy*. 2008;63(10):1301-9.
3. Lai CKW, Beasley R, Crane J, Foliaki S, Shah J, Weiland S, et al. Global variation in the prevalence and severity of asthma symptoms: Phase Three of the International Study of Asthma and Allergies in Childhood (ISAAC). *Thorax*. 2009;64(6):476–83.
4. Leynaert B, Neukirch F, Demoly P, Bousquet J. Epidemiologic evidence for asthma and rhinitis comorbidity. *J Allergy Clin Immunol*. 2000;106(5):S201-5.
5. Cook M, Douglas JA, Mallon D, Mullins R, Smith J, Wong M. *The Economic Impact of Allergic Disease in Australia: Not to Be Sneezed At* [Report]. Balgowlah (AUST): Australasian Society of Clinical Immunology and Allergy; 2007.
6. Australian Institute of Health and Welfare. *Allergic Rhinitis ('Hay Fever') in Australia*. Catalogue No.: ACM 23. Canberra (AUST): AIHW; 2011.
7. Bauchau V, Durham SR. Prevalence and rate of diagnosis of allergic rhinitis in Europe. *Eur Respir J*. 2004;24(5): 758–64.
8. Davies JM, Li H, Green M, Towers M, Upham JW. Subtropical grass pollen allergens are important for allergic respiratory diseases in subtropical regions. *Clin Transl Allergy*. 2012;2:4.
9. Medek DE, Kljakovic M, Fox I, Pretty DG, Prebble M. Hay fever in a changing climate: Linking an internet-based diary with environmental data. *Ecohealth*. 2012;9(4):440-7.
10. Scala E, Alessandri C, Bernardi ML, Ferrara R, Palazzo P, Pomponi D, et al. Cross-sectional survey on immunoglobulin E reactivity in 23 077 subjects using an allergenic molecule-based microarray detection system. *Clin Exp Allergy*. 2010;40(6):911–21.
11. Suphioglu C, Singh MB, Taylor P, Bellomo R, Holmes P, Puy R, et al. Mechanism of grass-pollen-induced asthma. *Lancet*. 1992;339(8793):569-72.
12. Devillier P, Le Gall M, Horak F. The allergen challenge chamber: A valuable tool for optimizing the clinical development of pollen immunotherapy. *Allergy*. 2011;66(2):163–9.
13. Erbas B, Lowe AJ, Lodge CJ, Matheson MC, Hosking CS, Hill DJ, et al. Persistent pollen exposure during infancy is associated with increased risk of subsequent childhood asthma and hayfever. *Clin Exp Allergy*. 2013;43(3):337–43.
14. Darrow LA, Hess J, Rogers CA, Tolbert PE, Klein M, Sarnat SE. Ambient pollen concentrations and emergency department visits for asthma and wheeze. *J Allergy Clin Immunol*. 2012;130(3):630-8.
15. Erbas B, Chang J-H, Dharmage S, Ong EK, Hyndman R, Newbigin E, et al. Do levels of airborne grass pollen influence asthma hospital admissions? *Clin Exp Allergy*. 2007;37(11):1641–7.
16. Bellomo R, Gigliotti P, Treloar A, Holmes P, Suphioglu C, Singh MB, et al. 2 consecutive thunderstorm associated epidemics of asthma in the city of Melbourne – the possible role of rye grass-pollen. *Med J Aust*. 1992;156(12):834-7.
17. Marks GB, Colquhoun JR, Girgis ST, Hjelmroos Koski M, Treloar ABA, Hansen P, et al. Thunderstorm outflows preceding epidemics of asthma during spring and summer. *Thorax*. 2001;56(6):468–71.
18. Howden ML, McDonald CF, Sutherland MF. Thunderstorm asthma – a timely reminder. *Med J Aust*. 2011;195(9):512-3.
19. Taylor PE, Flagan RC, Valenta R, Glovsky MM. Release of allergens as respirable aerosols: A link between grass pollen and asthma. *J Allergy Clin Immunol*. 2002;109(1):51-6.
20. León-Ruiz E, Alcázar P, Domínguez-Vilches E, Galán C. Study of Poaceae phenology in a Mediterranean climate. Which species contribute most to airborne pollen counts? *Aerobiologia*. 2011;27(1):37–50.
21. Spieksma FThM, Corden JM, Detandt M, Millington WM, Nikkels H, Nolard N, et al. Quantitative trends in annual totals of five common airborne pollen types (*Betula, Quercus,* Poaceae, *Urtica*, and *Artemisia*), at five pollen-monitoring stations in western Europe. *Aerobiologia*. 2003;19(3-4):171–84.
22. Smith M, Emberlin J. Constructing a 7-day ahead forecast model for grass pollen at north London, United Kingdom. *Clin Exp Allergy*. 2005;35(10):1400–6.
23. Ong EK, Singh MB, Knox RB. Grass pollen in the atmosphere of Melbourne: Seasonal distribution over nine years. *Grana*. 1995;34(1):58-63.
24. Haberle SG, Bowman DMJS, Newnham RM, Johnston FH, Beggs PJ, Buters J, et al. The macroecology of airborne pollen in Australian and New Zealand urban areas. *PLoS ONE*. 2014;9(5):e97925.
25. Andersen TB. A model to predict the beginning of the pollen season. *Grana*. 1991;30(1):269–75.
26. Galán C, Emberlin J, Domínguez E, Bryant RH, Villamandos F. A comparative analysis of daily variations in the Gramineae pollen counts at Córdoba, Spain and London, UK. *Grana*. 1995;34(3):189–98.
27. Jato V, Rodríguez-Rajo FJ, Alcázar P, De Nuntiis P, Galán C, Mandrioli P. May the definition of pollen season influence aerobiological results? *Aerobiologia*. 2006;22(1):13–25.
28. Khwarahm N, Dash J, Atkinson PM, Newnham RM, Skjøth CA, Adams-Groom B, et al. Exploring the spatio-temporal relationship between two key aeroallergens and meteorological variables in the United Kingdom. *Int J Biometeorol*. 2014;58(4):529–45.
29. Ribeiro H, Oliveira M, Ribeiro N, Cruz A, Ferreira A, Machado H, et al. Pollen allergenic potential nature of some trees species: A multidisciplinary approach using aerobiological, immunochemical and hospital admissions data. *Environ Res*. 2009;109(3):328–33.
30. Frenguelli G, Passalacqua G, Bonini S, Fiocchi A, Incorvaia C, Marcucci F, et al. Bridging allergologic and botanical knowledge in seasonal allergy: A role for phenology. *Ann Allergy Asthma Immunol*. 2010;105(3):223-7.
31. Bureau of Meteorology. *El Niño Example* [Internet]. Melbourne (AUST): BOM; 2008 April 2 [cited 2014 Sep 2]. Available from: http://www.bom.gov.au/climate/about/?bookmark=elninoexample
32. American Academy of Allergy, Asthma and Immunology. *About the National Allergy Bureau* (NAB) [Internet]. Milwaukee (WI): AAAAI; 2014 [cited 2014 Jun 3]. Available from: http://www.aaaai.org/global/nab-pollen-counts/about-the-nab.aspx
33. European Aeroallergen Network. *Welcome to the EAN Database* [Internet]. Vienna (AUT): EAN; 2014 [cited 2014 Jun 3]. Available from: https://ean.polleninfo.eu/Ean/
34. Green BJ, Dettmann ME, Rutherford S, Simpson RW. Airborne pollen of Brisbane, Australia: A five-year record, 1994-1999. *Grana*. 2002;41(4):242-50.
35. Hasnain SM, Katelaris CH, Newbegin E, Singh AB. *Aeroallergen Monitoring Standard for The Asia Pacific Region: A WAO Manual for the Use of the Burkard Volumetric Spore Trap and Burkard Personal Volumetric Air Sampler*. Milwaukee (WI): World Allergy Organization; 2007 [cited 2014 Jun 3]. Available from: http://www.worldallergy.org/esp/ptm_2007.pdf
36. Vicendese D, Olenko A, Dharmage S, Tang M, Abramson M, Erbas B. Modelling and predicting low count child asthma hospital readmissions using General Additive Models. *Open J Epidemiol*. 2013;3(3):125-34.
37. Beggs PJ. Impacts of climate change on aeroallergens: past and future. *Clin Exp Allergy*. 2004;34(10):1507-13.
38. Ziska LH, Beggs PJ. Anthropogenic climate change and allergen exposure: The role of plant biology. *J Allergy Clin Immunol*. 2012;129(1):27-32.
39. Ziska L, Knowlton K, Rogers C, Dalan D, Tierney N, Elder MA, et al. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proc Natl Acad Sci U S A*. 2011;108(10):4248–51.
40. Ziello C, Sparks TH, Estrella N, Belmonte J, Bergmann KC, Bucher E, et al. Changes to airborne pollen counts across Europe. *Plos One*. 2012;7(4):e34076.
41. Katelaris CH, Burke TV, Byth K. Spatial variability in the pollen count in Sydney, Australia: Can one sampling site accurately reflect the pollen count for a region? *Ann Allergy Asthma Immunol*. 2004;93(2):131–6.
42. Rieux C, Personnaz M-B, Thibaudon M. Spatial variation of airborne pollen over south-east France: Characterization and implications for monitoring networks management. *Aerobiologia*. 2008;24(1): 43–52.
43. Holt KA, Bennett KD. Principles and methods for automated palynology. *New Phytol*. 2014;203(3): 735–42.
44. Jalaludin B, Smith M, O'Toole B, Leeder S. Acute effects of bushfires on peak expiratory flow rates in children with wheeze: A time series analysis. *Aust N Z J Public Health*. 2000;24(2):174–7.