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Landscape of ecological research in Australia: A bibliometric analysis of trends in research output and hotspots of research from 1991 to 2010

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Abstract The spatial distribution and density of scientists can have important implications for key aspects of scientific processes, such as innovation, networking, rates of knowledge exchange and success in large competitive grants. In this paper, we examine the research output of different research organizations and universities in Australia, with the aim of identifying hotspots of ecological research and how these hotspots have changed over the last 20 years. We used publications from 10 reputable peer-reviewed international journals as a measure of research output. We identified a number of ecology hotspot clusters. Some clusters have developed significantly over the last 20 years, while others have declined in output over time. The University of Sydney, University of Queensland, James Cook University and Melbourne University had the largest output levels among universities. Results also showed large increases in output over the last 5-year period (2006–2010), possibly because of the impending introduction of the Excellence in Research for Australia.

Key words: Australia, ecological research, hotspot, research output, spatial distribution.

INTRODUCTION

Academic knowledge is a key contributor to economic and social development of societies all over the world. As the primary custodian and developer of academic knowledge, higher learning institutions, such as universities, have come under increasing attention to undertake and disseminate research. The relevance of research has also become a primary focus. Traditionally, universities were seen as having a duty to teach and carry out research for growth of academia (Colombo *et al*. 2010); however, this role has evolved over time and currently universities are also expected to contribute directly to economic growth (Etzkowitz 2000, 2002; Nilsson *et al*. 2010). These developments in the expectations of universities have led to a more entrepreneurial model of academic research. Universities have accepted that they have a responsibility to contribute directly to social and economic development of the society, apart from their traditional role of teaching and undertaking research for growth of academia or for self-interest (Etzkowitz 2002). Etzkowitz *et al*. (2000) incorporate this new paradigm in their triple helix model description of entrepreneurial universities and discuss the academic–industry–government relations and the push towards knowledge-based innovations.

With the introduction of the entrepreneurial model, considerable effort has been expended into finding means of quantifying research output so as to provide an objective rationale for the allocation of resources. Universities have also come under pressure to show that they are engaged in research and disseminating this research. The evaluation of academic research has also become an important tool in the monitoring and motivation of academics. It provides valuable information about the quality of academic work, and is an important component in the allocation of resources, rewards and promotions. One *de facto* means of quantifying research and research output is through publications, more specifically peer-reviewed journal publications. Increasingly, research output is measured in terms of citations and publications per dollar.

In Australia, the Commonwealth Government recently introduced the Excellence in Research for Australia (ERA) to monitor and stimulate the research performance of Australian universities (Hicks 2009). Future funding was tied to performance, specifically performance in the research domain. Performance was evaluated using a number of indicators, the main one being a four-tiered journal ranking that served as a proxy for the quality of research output. The ERA scheme has been modified recently to exclude the ranking of journals, so the emphasis now is on the

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number of publications in a defined set of journals and their citations, hence bibliometrics will play an important role in resource allocation for Australian universities in the future.

Apart from its use in resource allocation and ranking of institutions, bibliometrics can be used to gain knowledge of the spatial distribution and clustering of productive research areas. The spatial distribution and density of scientists and research groups impact on key aspects of scientific processes, such as innovation, networking and rates of knowledge exchange (Ponds *et al.* 2007). According to Katz (1994), geographic proximity positively influences the intensity and frequency of scientific collaboration. Knowledge of the spatial distribution and density of highly productive research centres can reveal hotspots of research and can encourage greater collaboration and networking, as networking is seen as an important means of enhancing scientific research and quality (Andersson & Persson 1993).

In this paper, we examine one measure of research output, namely publications in a set of 10 reputable peer-reviewed international ecology-related journals. The aim of the research was to identify hotspots of ecological research in Australia, the research output of some key institutions and universities, the trend in this research output over the last 20 years in terms of total output as well as output per contributing author, and the overall growth of the literature in ecology. We were interested in the variability of research output in the ecology discipline in Australia and also among the universities and research organizations. According to Hall (1989), the growth in literature in a field has been shown to be an effective science indicator. To determine the research output of different regions in Australia, author institutions were grouped according to their postcode regions and hotspot analysis was used to identify clusters of highest productivities. This approach has been widely used by a number of other researchers, for example Macri and Sinha (2002), Towe and Wright (1995), Bairam (1996), Gibson (2000) and King (2001). Research output of individual institutions was determined by grouping output of multiple campuses together. The aim of the work presented here was to identify clusters of high research output and research output of various institutions, not to rank institutions. The research outputs of clusters of high output areas and institutions were not corrected for staff numbers, commonwealth funding allocation and other external grant availability, so the results here should not be used to rank institutions. Productivity is not a measure of output alone, it is dependent on many other factors, including level of funding, grant income, number of academics in the relevant field, the emphasis placed on that field of research by the relevant research institutions and seniority of academics. These are complex factors and obtaining relevant data on all these is very difficult, or almost impossible. This is one of the reasons why we did not look at productivity per se, but instead looked at output only and how these outputs have changed over the last 20 years.

METHODS

Data

To construct the database to answer our questions and have confidence in the results, it was important to pay attention to three issues. First, we had to select a reliable source of information; second, we had to select a representative set of journals upon which the whole analysis would be based; and third, we had to correctly identify and allocate each scholar's publications to their respective postal codes and institutions.

For our analysis, we used a combination of electronic databases, journal home pages listing abstracts and full papers in some cases, and hard copies of journals as a last resort where the required information could not be gleaned from the electronic databases or journal home pages. To obtain a representative set of journals, we undertook a small survey of 15 ecologists, asking each to provide a list of 10 journals in which Australian ecology researchers were most likely to publish their research results. Note that we specifically mentioned 'Australian' as we were interested in research hotspots and output of Australian researchers. From this survey, we selected the top 10 nominated journals. To assist the survey participants, we provided a list of 23 journals, but we were very clear that they could nominate other journals of their choice. None of the survey participants was informed about the purpose of the survey to avoid any notion of bias creeping into the selection. It should be noted that our aim was to capture the largest possible proportion of Australian ecology publications, hence the impact factor of the journal was not an issue. We could have selected the top 10 journals by impact factor, but this would have captured a much smaller proportion of Australian publications, hence an impact factor-based selection was not utilized. The list of 23 journals and the final 10 selected journals are given in Table 1.

The *Web of Science* database was used to extract every authors' institution affiliation and postcode information for all papers. For some journals, full author affiliation information was not available from the *Web of Science* database and, in such cases, journal home pages or hard copies of journals were used. For every publication where one of the authors had listed an Australian institution as his/her primary address, the publication year, number of authors, number of Australian authors, whether the first author was Australian, the postal code and the institution name were recorded. Also, where an author had more than one address listed, only the first address was used.

To calculate research output, publication data can be allocated using two basic approaches. The first is the flow approach (Harris 1988), which assigns research output according to the authors' affiliation at the time of publication. This means that the publication stays at the institution where the author(s) was/were based at the time of publication. The second, the stock approach (Towe & Wright

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Table 1. List of 23 journals that was used in the survey to find the 10 journals in which Australian ecologists were most likely to publish, with the final 10 selected in bold

Acta Oecologica	***Ecology***
American Naturalist	***Ecology Letters***
Annual Review of Ecology, Evolution and Systematics	*Ecosystems*
Austral Ecology (Australian Journal of Ecology)	***Functional Ecology***
Behavioural Ecology	***Journal of Applied Ecology***
Biodiversity & Conservation	***Journal of Ecology***
Biological Conservation	*Landscape Ecology*
Conservation Biology	*Molecular Ecology*
Ecography	***Oecologia***
Ecological Applications	***Oikos***
Ecological Modelling	*Trends in Ecology and Evolution*
Ecological Monographs	*PLoS ONE*

1995; Bairam 1996, 1997), involves assigning research output to the authors' current affiliation. This is justified on the basis that when a researcher moves from one institution to another, he/she takes the human capital. For this study, the flow approach was used as we were not interested in the research output of individuals, but of institutions and postal code regions during a specific period of time. The aim was to find the hotspots of ecology research at specific periods in time.

Postcode data for all 2516 regions of Australia for 2011, in the form of Environmental Systems Research Institute Inc. (ESRI) shapefiles, were obtained from the Australian Bureau of Statistics.

Allocating research output

Weighting of papers is often controversial, especially when rankings of authors or institutions are at stake. One can allocate equal weights to all authors or assign a higher weight to the primary author and decreasing amounts to the secondary authors. Sutter and Kocher (2001) found very high correlation between the different approaches, and deemed the issue of weighting much less important than it is made out to be. Also, a lot of differences concerning weights are connected to article length and type of article. In this research, only research articles were recorded, so the second concern does not arise. For the length of the article, we treated all articles the same as the time devoted to writing a paper generally constitutes only a small fraction of the entire research process. This view is reinforced by Sutter and Kocher (2001). However, Kalaitzidakis *et al.* (1999) counted pages per article and converted all articles to a selected journal format, implying a positive correlation between the length of a paper and the resources expended to obtain its scientific content. This approach is difficult to justify as many high impact journals have strict page limits and length of articles do not correlate with resources expended.

The total weight per paper can be considered to be one (100%); therefore, each single authored paper was given a weight of 1.0, and this weight was allocated to the sole author and to the institution to which he/she belonged. For multiple-authored papers, a weight of 0.75 was allocated to the first author and the remaining 0.25 was divided equally among all other authors. The weight allocated to the first author can be debated, but we followed the suggestion of Pokallus *et al.* (2011). As we were interested in the research output and hotspots within Australia, all weightings accrued to foreign authors were discarded. The allocated weights were added to give overall weighted number of papers for each postcode and each institution, and then grouped into 5-year clusters. The 5-year clusters were 1991–1995, 1996–2000, 2001–2005 and 2006–2010. The postcode-based values were then used for cluster and hotspot analysis, while the institution-based values were used to determine institution-based research output and trends in research output.

Hotspot analysis

The Getis–Ord G*i** statistical approach (Getis & Ord 1992), with the 'polygon contiguity' option in ArcGIS (ESRI 2010), was used to relate research output locations to postcodes. The polygon contiguity option within ArcGIS uses all surrounding postcodes that share their border with the input polygon. The other common option, fixed distance band, was not used as the postcode areas vary greatly in size, and calculating hotspots based on a fixed distance option would have included a larger number of surrounding postcodes for smaller postcode polygons and very few for larger postcode polygons. The Getis–Ord G*i** statistic (Eqn 1) works by looking at each feature within the context of neighbouring features and identifies those clusters of points with values higher in magnitude than you might expect to find by random chance (ESRI 2010). This statistic was applied to model the total weighted output at postcode level, where values of the output were high and geographically homogenous.

$$G_i^\star = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (1)$$

where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between i and j, and n is equal to the total number of features.

The output of the Getis–Ord G*i** statistic is a *z*-score and *P*-value for each postcode. The *z*-score represents the statistical significance of clustering for a specified distance. Postcodes with high *z*-scores and small *P*-values indicate spatial clustering of a high level of research output, while postcodes with low *z*-scores and high *P*-values indicate lower levels of spatial clustering of output. All postcodes were classified based on *z*-score values, with high *z*-scores having higher output and low *z*-scores indicating lower output areas.

Based on the hotspot analysis, the outputs for each of the hotspot regions were grouped together. For example, for the Canberra region, hotspot analysis showed a cluster around postcodes 2600–2607, so the output of these postcodes were added to create a hotspot region. This grouped a number of

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research institutions in one region including Australian National University, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Defence Force Academy. This now gave us the total research output for the selected hotspot regions. The proportion of the total Australian output for each hotspot region was also calculated. This was achieved by dividing the output of each region by the total research output for Australia. This resulted in the percentage of output commanded by each of the hotspot regions.

Finally, we used the number of authors from each institution as a normalizing factor to determine research output per contributing author. We used the data for years 1990, 2000 and 2010 as representative samples and, for each of these years and each institution, determined the number of unique authors contributing to the research output. We then divided the research output for each institution by the number of unique authors for that institution to provide an index that removes the effect of institution size. However, this index should not be misconstrued as an indicator of productivity as the data do not give the number of ecologists at each institution and not all ecologists publish.

RESULTS

Overall, over the 20-year study period, there were 3157 articles with at least one author whose primary address was in Australia (Table 2). There was an average of 158 papers per year. The highest number of papers was in 2008 and lowest in 1992 (Fig. 1). There was a general trend of increasing number of publications over the 20-year period. *Austral Ecology* (formerly *Australian Journal of Ecology*) had the highest number of publications, with 997 (32%) of articles. This was to be expected as *Austral Ecology* is the official journal of the Ecological Society of Australia and is the main ecological journal in Australia. *Ecology Letters* had the lowest number of papers (68). In terms of growth in publications, the output was almost constant between 1990 and 1994, and then there was a steady increase in output until 2010 (Fig. 1). A greater than average jump in publications was noticed in 2000 and in 2008.

During the early to mid-1990s almost all of the research output had an author whose primary address was in Australia. There were only a couple of articles each year where the primary author was from outside Australia. From 1996 onwards, there were an increasing number of papers from researchers whose primary addresses were not in Australia and this gap has widened every year since then.

The total output, in terms of weighted papers over the 20-year study period, was 2741. This means that 416, or 13.2%, of the total weighted papers were attributable to non-Australia-based authors. The research output from 1991 to 1995 was 515, from 1996 to 2000 was 610, from 2001 to 2005 was 681 and from 2006 to 2010 was 937. The overall trend in output was a general increase over the 20 years; however, there was a bigger jump in output (37%) during the last 5-year period. Results also show that most of the productive regions were around the big cities (Fig. 2). The hotspots were clustered around Canberra, Sydney, Melbourne, Brisbane, Tasmania, Adelaide, Perth, Darwin, Cairns, Townsville and Armidale.

Based on the *z*-scores, we identified 11 clusters as significant hotspots of ecology research in Australia (Fig. 2). The Sydney region (6) had the highest research output (608). This was 23% of the total Australian output. This was followed by Melbourne Metro (8) with 375 (14%) and Canberra (7) with 345 (13%) weighted papers.

The research output and the proportion of national output for each 5-year period of each of the 11 postcode clusters identified by hotspot analysis are shown in Figures 3 and 4. During 1991–1995 and 1996–2000, the Sydney hotspot cluster (6) was the most productive (121 and 148 weighted papers, 23.5% and 24%), followed by the Canberra region (7) (81 weighted papers in both periods, 16% and 13%) and

Table 2. Breakdown of the number of papers by journal for the 10 selected journals for the 20-year period

Journal	Total number of papers
Austral Ecology (Australian Journal of Ecology)	997
Biological Conservation	497
Oecologia	427
Journal of Applied Ecology	248
Ecology	226
Conservation Biology	217
Oikos	209
Functional Ecology	153
Journal of Ecology	115
Ecology Letters	68
	3157

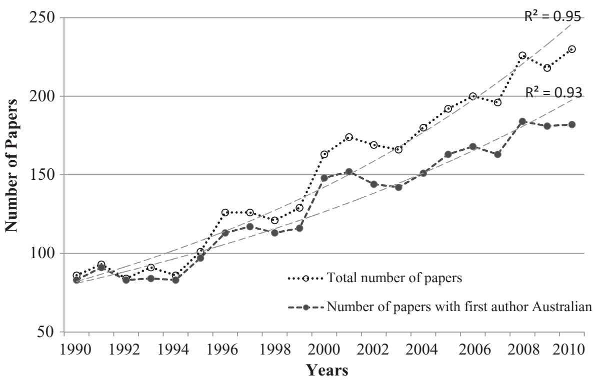

Fig. 1. Trends in total number of papers with at least one author with an Australian address.

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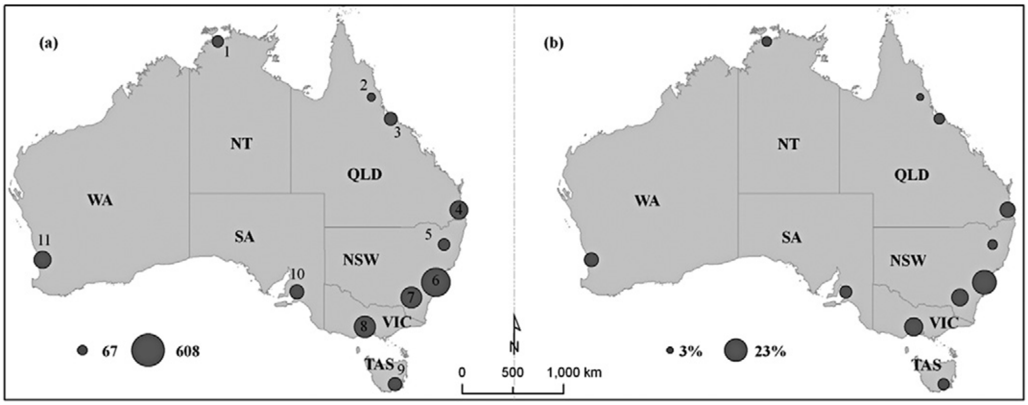

Fig. 2. (a) Total weighted research output for the main research clusters identified using hotspot analysis and (b) proportion of national output for each research hotspot cluster. NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia.

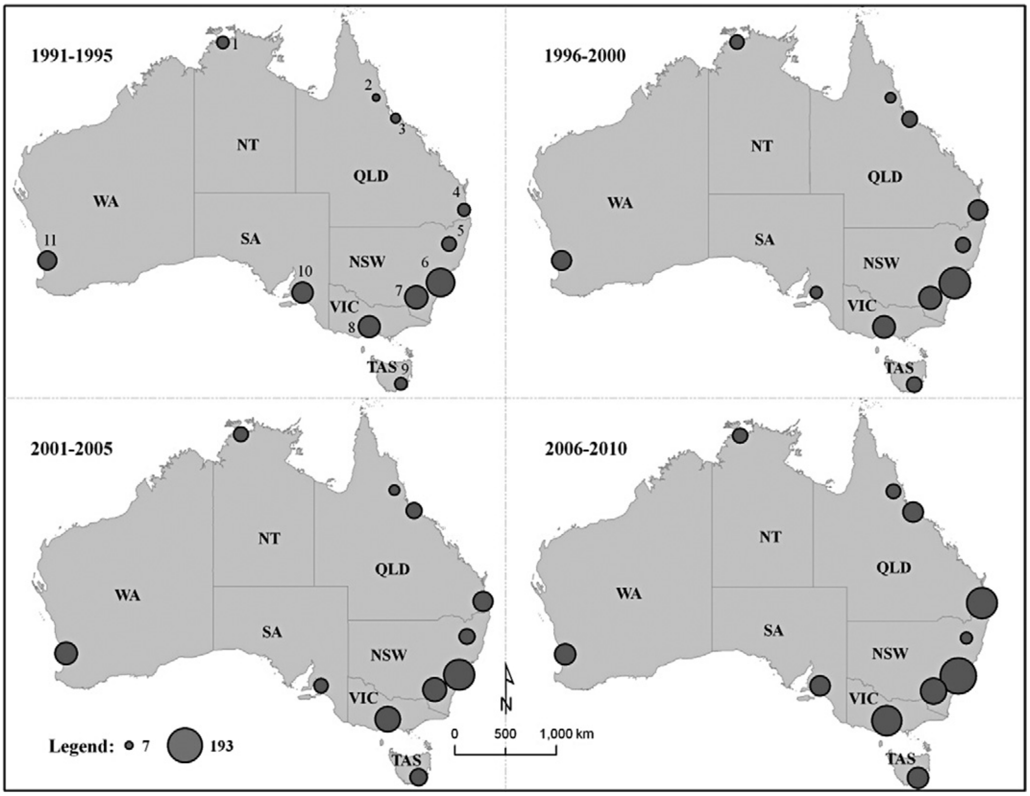

Fig. 3. Research output, grouped in 5-year blocks, showing how output changed for each research cluster and in comparison with other clusters over the 20-year study period. The legend is the same for all four maps. NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia.

Melbourne Metro (8) (67 and 74 weighted papers, 13% and 12%). During 2000–2005, the Sydney hotspot cluster again had the highest output (146 weighted papers, 21%), followed by Melbourne Metro (96 weighted papers, 14%) and Canberra (81 weighted papers, 12%). The Brisbane cluster was a big improver during the 2006–2010 period, where it had an output of 141 (15%), coming second to Sydney (193, 21%). Melbourne Metro slipped one position down, with 138 weighted papers (14.5%) and Canberra fourth (101, 11%). The Sydney cluster had the most output during all 4 study periods.

Of the other hotspot clusters, Cairns (2), Townsville (3) and Tasmania (9) increased their output and the proportion of national output during the 20-year period. Cairns went from 7.3 (1.4%) in 1991–1995 to

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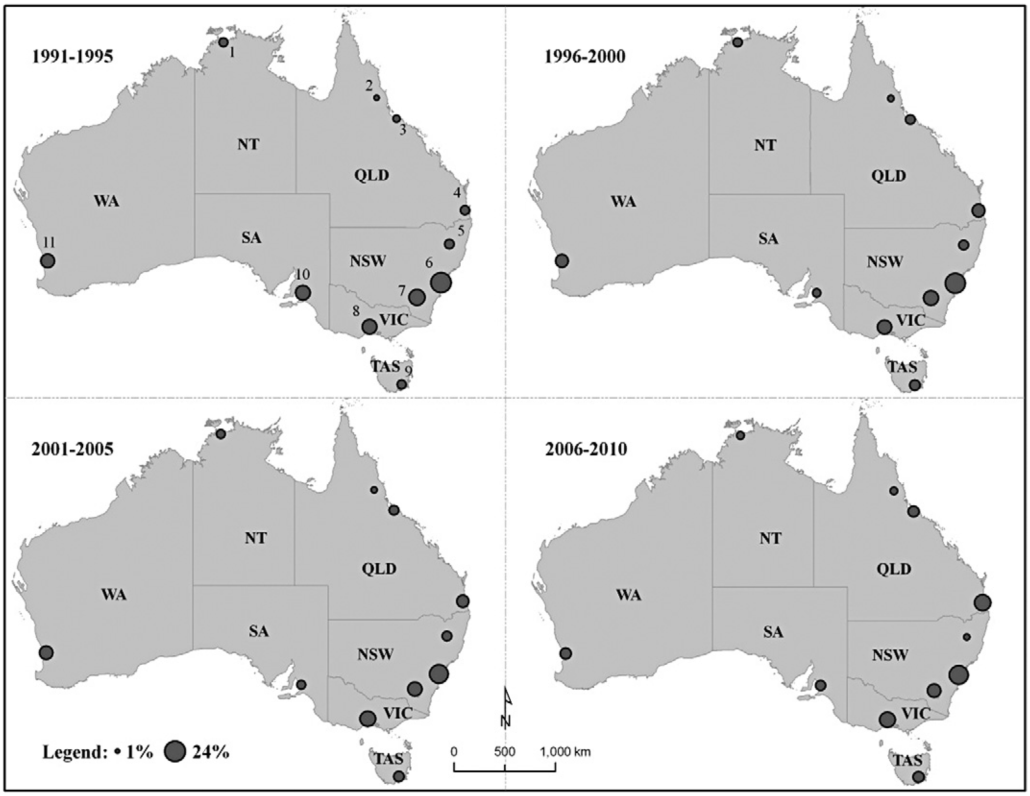

Fig. 4. Research output for each cluster, in terms of percentage of national total output, by 5-year blocks showing how individual cluster proportions changed in comparison with other clusters over the 20-year study period. The legend is the same for all four maps. NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia.

31 (3.3%) in 2006–2010; Townsville from 15 (2.9%) to 62 (7%) and Tasmania from 23 (4.5%) to 65 (7%) over the same period. On the other hand, the Armidale (5) cluster decreased in both absolute research output and proportion of national output. Its output during 1991–1995 was 30 (5.8%), while during 2006–2010 it had gone down to 21 (2.2%).

Table 3 shows the research output for 33 of the highest output institutions. CSIRO had the highest total output and also the highest output during every 5-year block. Of the universities, the University of Sydney had the highest total output and the highest output during each of the 5-year blocks. Australian National University was next, followed by James Cook University and the University of Queensland in terms of total output over the 20-year period. However, if one looks at the individual 5-year blocks, The University of Queensland is second only to University of Sydney in terms of research output during the 2006–2010 period. The University of Queensland had a low output of 8.2 during 1991–1995, but increased this to 26.9 during 1996–2000, 28.1 during 2001–2005 and almost a three-fold increase to 75.6 during 2006–2010. The University of Melbourne had a similar rise, going from 18.3 during 1991–1995 to 62.5 during 2006–2010. Similarly James Cook University went from 8.0 during 1991–1995 to 72.1 during 2006–2010.

This level of increase was not seen for all universities, with some remaining stagnant while others had reduced output. Curtin University and the University of New England are two examples where output actually decreased during every time period used in this research.

The research output for selected institutions, normalized by the number of contributing authors, is given in Figure 5. Data for years 1990, 2000 and 2010 were used as representative samples. There is large variability in research output per author, both between institutions and within institutions for the three study years. The mean output varies from 0.24 to 0.71 papers per author. Charles Darwin University, University of Western Australia and the University of Sydney had the highest outputs on this measure, while Griffith University and Curtin University were at the lower end of the range. Most other institutions had values between 0.5 and 0.6.

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Table 3. Research output in terms of weighted papers for 33 institutions with the highest output

No.	Institution	1991–1995	1996–2000	2001–2005	2006–2010	Total output
1	Commonwealth Scientific and Industrial Research Organisation	76.8	74.7	70.1	143.1	364.6
2	U Sydney	51.1	52.1	49.3	80.9	233.5
3	Australian National University	43.7	39.0	42.8	52.3	177.8
4	James Cook U	8.0	30.1	35.3	72.1	145.6
5	U Queensland	8.2	26.9	27.8	75.6	138.5
6	U Melbourne	18.3	26.3	28.1	62.5	135.2
7	Macquarie U	22.3	34.5	38.8	27.4	123.0
8	U Tasmania	15.7	27.1	28.3	45.8	116.9
9	U New England	29.9	29.5	24.3	19.2	102.9
10	Monash U	33.8	17.8	22.9	24.2	98.6
11	U New South Wales	18.5	17.7	20.2	28.2	84.6
12	U Adelaide	10.4	12.1	22.2	23.4	68.2
13	U Western Australia	13.1	21.8	16.4	15.8	67.1
14	Charles Darwin U	7.6	17.8	15.2	18.9	59.4
15	Griffith U	7.0	11.0	17.5	23.5	59.1
16	U Wollongong	11.0	7.0	9.6	23.8	51.4
17	La Trobe U	7.8	16.0	13.6	9.0	46.4
18	Curtin U	16.4	10.2	9.1	6.8	42.4
19	Flinders U	8.8	9.2	5.7	11.0	34.6
20	U Technology Sydney	4.8	6.0	8.2	9.0	27.9
21	Charles Sturt U	0.0	3.0	8.7	14.8	26.4
22	Murdoch U	3.6	3.5	8.3	8.4	23.8
23	Australian Museum	6.6	3.8	4.7	4.5	19.5
24	U Canberra	4.1	0.8	1.7	12.0	18.6
25	Deakin U	0.0	2.1	6.2	8.9	17.2
26	Edith Cowan U	0.0	1.5	7.7	6.0	15.2
27	U Western Sydney	0.0	1.8	6.0	5.0	12.8
28	Queensland University of Technology	0.0	2.1	1.1	6.6	9.8
29	U Newcastle	0.0	0.8	3.8	0.0	4.5
30	U Southern Qld	0.0	1.0	0.0	2.0	3.0
31	Royal Melbourne Institute of Technology	0.0	0.8	0.3	1.8	2.8
32	U South Australia	0.0	0.0	0.1	1.2	1.2
33	Government Depts. and other Institutes	86.0	102.2	126.7	93.2	408.0
	Total	513	610	681	937	2741

The output has been divided into 5-year blocks to gauge trends within institutions.

DISCUSSION

Our analysis of publications in the selected 10 ecology related journals shows that there is considerable spatial heterogeneity in research output in the ecology discipline. There are regions of high output and these have changed over time. Most of the high output regions are around the cities of Brisbane, Sydney, Canberra, Melbourne, Adelaide, Perth, Armidale, Darwin and Townsville. This is to be expected as most of the research organizations and universities are based in these areas. The Sydney region had the highest output, followed by Canberra, Melbourne and Brisbane.

Over the 20-year study period, there were considerable changes in the regions that dominate in ecology research in Australia. However, the one region that has maintained its dominance in ecological research is the Sydney region (Region 6 in Figs 3,4). It had the highest output in each of the 5-year periods and its proportion of national output also remained the highest in each period. The high output in the Sydney region was mainly attributable to the University of Sydney. Brisbane was the biggest improver over this 20-year period, increasing its output from 24 weighted papers in 1991–1995 to 141 in 2006–2010. In terms of proportion of national output, it went from 4.6% to 15.1% over this same time period. This increase in total and percentage output was mainly due the large gains by the University of Queensland. Townsville is one other region that improved its share of research output over the study period. On the other hand, Perth and Melbourne regions maintained their share of the national output. Armidale and Adelaide had a decrease in their share of the national output. The changes in output levels of each of the areas could be due to changing staff levels, changes in research focus or movement of key staff.

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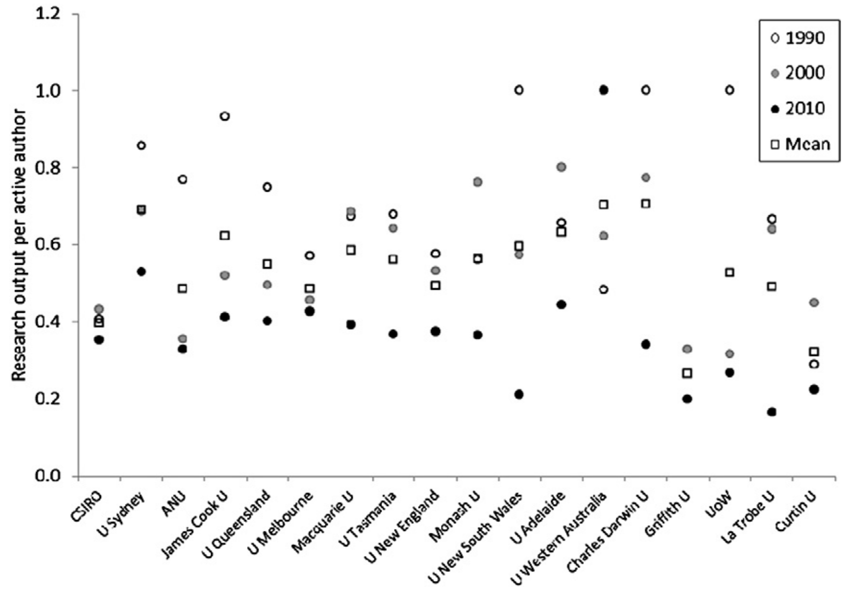

Fig. 5. Research output normalized by the number of authors for each institution for 1990, 2000 and 2010. ANU, Australian National University; CSIRO, Commonwealth Scientific and Industrial Research Organisation; UoW, University of Wollongong.

What is also important are the trends within each research institution. Figure 6 shows the trends as 5-year blocks for 18 of the most productive ecology research institutions in Australia. Varying trends are obvious from this graph. Some institutions have increased their research output during each of the time periods, some have stayed around the same level, while others have actually seen a decrease in output. James Cook University, University of Queensland, University of Melbourne, University of Tasmania, University of Adelaide and Griffith University have seen their total output increase during each 5-year block over the last 20 years. The standout performers over the last 5 years, in terms of large increases in output, are CSIRO, University of Sydney, James Cook University, University of Queensland, University of Melbourne and University of Tasmania. In terms of percentage increase, University of Queensland was at the forefront, with a 172% increase in the 2006–2010 period when compared with the previous 5-year period.

Of the 18 institutions shown in Figure 6, the two institutions that actually had a decline in output during every 5-year block over the 20 years were the University of New England and Curtin University. The University of New England was the fifth most productive institution during the 1991–1995 period; however, it has seen a gradual decline in its output in this discipline and is down to 14th position during 2006–2010.

Research output analysis as presented here can also be used by universities and research organizations to identify emerging research strengths as well as to identify those fields where they can become leaders in research. In Australia, a very large proportion of research funding is directed to the Group of Eight (Go8) universities as they have an established track record and are perceived to be much more productive than the other smaller universities. The analysis here shows that the Go8 does not necessarily hold a dominant position in ecological research in Australia. The University of Sydney, Australian National University, University of Queensland and University of Melbourne are four of the Go8 universities that have very high research outputs. The other four, Monash University, University of New South Wales, University of Adelaide and the University of Western Australia, have much lower levels of output; even lower than many of the smaller universities. James Cook University and the University of Tasmania have much higher output than these four universities. A similar trend appears when research output per author is taken into account (Fig. 5). Considering the mean number of papers per author, the top five institutions are Charles Darwin University, University of Western Australia, University of Sydney, University of Adelaide and James Cook University. If we consider more recent data, those of 2010, then the top five institutions based on papers per author are University of Western Australia, University of Sydney, University of Adelaide, University of Melbourne and James Cook University.

From Figure 5, we also see that there is a general trend of decreasing research output per contributing author for almost all the institutions. The output per author for 2010 is lower than that for 2000 for all

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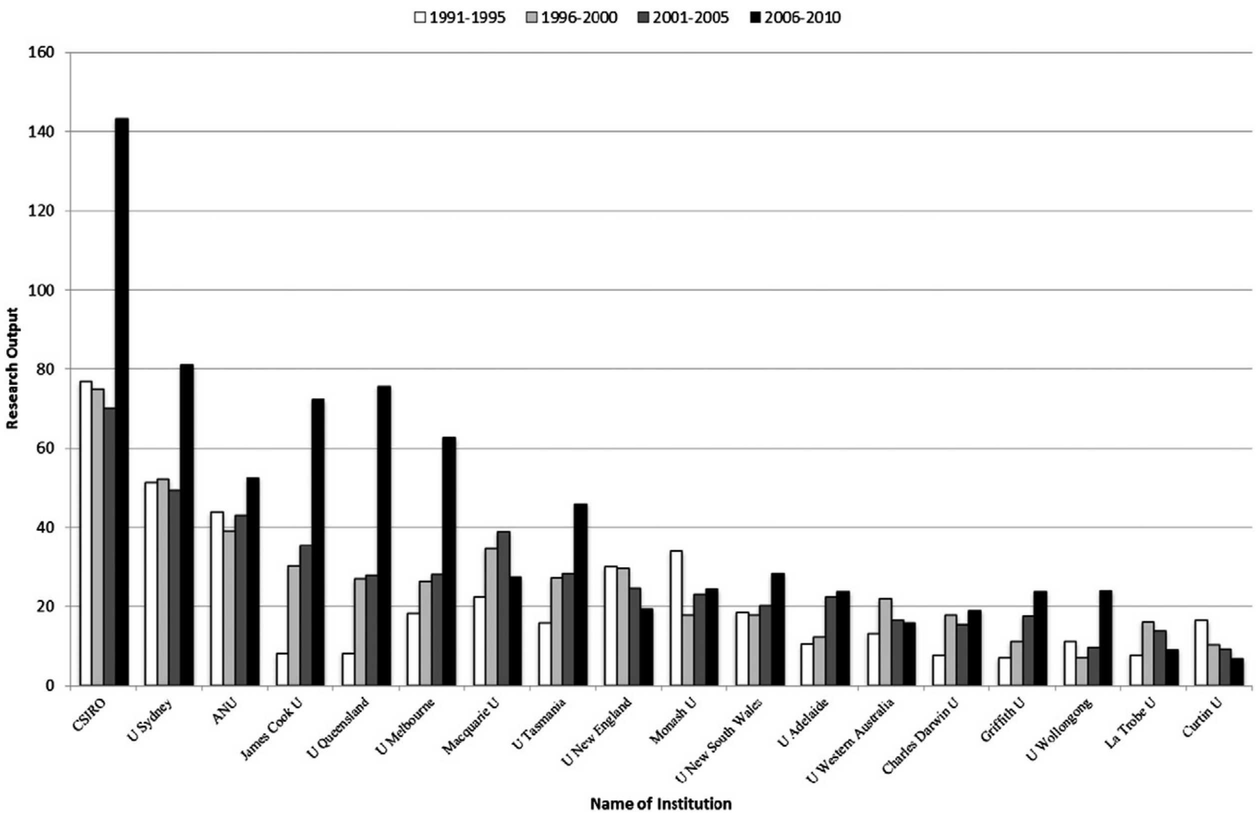

Fig. 6. Trends in research output for 18 institutions with the highest outputs over the last 20 years, with output grouped into 5-year blocks. ANU, Australian National University; CSIRO, Commonwealth Scientific and Industrial Research Organisation.

institutions except one (University of Western Australia) of the 19 institution results presented. So, while overall research output has consistently increased over the last 20 years, the output per author has actually decreased.

Figure 6 shows that universities such as the University of Wollongong have an emerging research strength in the field of ecology. While their research output was low for the first three 5-year periods (1991–2005), they had a large increase in output during the 2006–2010 period. This result could be due to the university management allocating additional resources in this discipline during this time period, and if so, it shows that the effort is paying off. However, if no extra emphasis was placed on the discipline during this period, then the figure clearly shows that this is an area where the university could allocate more resources in the future as it is showing great promise.

Conclusion

Quantification of the spatial arrangement of ecological research in Australia has highlighted a number of hotspots and revealed several regional centres of high ecological activity. A knowledge of such hotspots not only reveals the communities with high research output, but also helps in identifying those regions where fruitful research opportunities may exist. This information can direct collaborative research opportunities and sharing of resources and expertise. It can also be used by non-ecological organizations and companies that seek to utilize outside expertise to solve their own environmental problems or help in the decision-making process.

The growth in literature in ecology is a healthy sign for Australia. Total output increased from 416 weighted papers in 1991–1995 to 937 in 2006–2010, an increase of 125% over 20 years. There was also an increase in international interest in Australian ecological research. In 1991, there were only 3 out of 86 (3.5%) papers where the primary author did not have an Australian address, while in 2010, there were 48 out of 230 (20.9%) papers where the primary author did not have an Australian address. However, the research output per contributing author has declined over the last 20 years and this should be an issue of concern.

It is anticipated that publication rates would increase significantly because of the introduction of ERA, especially publications in those journals that form part of

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the ERA list. It is too early to deduce any trends from this study, as data from only a couple of post-ERA years form part of this study; however, a large increase in the output for a number of research organizations was noticed in the last 5-year period.

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