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Developmental Biology in Australia and New Zealand

BRIAN KEY[1,2]* and IAN MCLENNAN[3]

[1]Department of Anatomy and Developmental Biology, School of Biomedical Sciences, The University of Queensland, Brisbane, [2]Centre for Functional and Applied Genomics, University of Queensland, Brisbane Australia and [3]Neuromuscular Research Group, The Department of Anatomy and Structural Biology, The University of Otago, Dunedin, New Zealand

Developmental Biology in Australia

2001 was a special year in the Australian calendar – it was the centenary of the Australian federation. Prior to 1901 "Australia" existed as independent states with separate systems of government. Motivated by a strong sense of nationalism and a desire to protect against perceived outside threats, there was a gradual movement towards the end of the 19th century to the idea of creating a federation. Spearheaded by people such as Edmund Barton and Sir Henry Parkes, a series of federation conventions were held in the 1890s. By the end of 1899 all six Australian colonies (New South Wales, Victoria, South Australia, Tasmania, Queensland and Western Australia) voted in favour of a Federation and a Constitution Bill. After the Commonwealth of Australia was proclaimed by Queen Victoria in 1900, its inauguration took place on January 1st 1901 in Sydney (for further information see The Australia Bureau of Statistics web site http://www.abs.gov.au).

Australia is a constitutional democracy arising from the Commonwealth of Australia Constitution Act (1900). Government has five principal foundations: the Commonwealth constitution, legislation from Commonwealth, State and Territory parliaments, High Court judgements, State and Territory Constitutions, and conventions adopted from the Westminster system. Australia has a total population of 19,300,000 (December, 2000) distributed in six states: New South Wales (6,500,000), Victoria (4,800,000), Queensland (3,600,000), Western Australia (1,900,000), South Australia (1,500,000) and Tasmania (500,000); and in two self-governing territories: Australian Capital Territory (300,000) and Northern Territory (200,000). Today the fastest growing state is Queensland (19% of total population) with an annual growth rate of 1.6%.

In many instances the figures presented below concerning the current state of funding of higher education institutes reveals that the Universities of Sydney, Melbourne and Queensland are three of Australia's top ranked institutions. It is not surprising that these three Universities are among the oldest in Australia's history. The University of Sydney (http://www.usyd.edu.au/) was established in 1850 and although a mere youngest in comparison to some of Europe's institutions it is Australia's oldest university. It began teaching in 1852 and offered Bachelor of Arts degree where studies could be undertaken in Science. At about the same time that the University was being established, a medical school was independently formed at the Sydney infirmary (http://www.med.usyd.edu.au/). It was not until 1883 that studies in

Abbreviations used in this paper: CMRI, Children's Medical Research Institute; HRC, Health Research Council ; JCSMR, John Curtin School of Medical Research ; RSBS, Research School of Biological Sciences; VCCRI, Victor Chang Cardiac Research Institute.

***Address correspondence to:** Dr. Brian Key. Department of Anatomy and Developmental Biology, School of Biomedical Sciences, The University of Queensland Brisbane, 4072, Australia. Fax: +61-7-3365-1299. e-mail: brian.key@uq.edu.au

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medicine were introduced to the curriculum at the University. The first part of the Anderson Stuart building which housed the Faculty of Medicine was completed in 1891. Anderson Stuart from Edinburgh University was appointed as the first Professor of Anatomy and Physiology. He was to play an instrumental role in establishing the Medical School and retired in 1920 after 30 years as the Dean. Today researchers in developmental biology in the School of Biomedial Sciences of the Medical Faculty are still housed in the Anderson Stuart Building. The Faculty has a prominent history in development biology and its earlier related fields. Of particular note are the studies by Joseph Shellshear (Professor of Anatomy) and Raymont Dart on the origin of the motor neuroblasts in the neural tube published in 1922 in the Journal of Anatomy. While the results of their studies were subsequently found to be incorrect, these authors contributed to an interesting debate of the time. Dart's fame lay in other fields and he went on to become a noted anthropologist and paleontologist.

The University of Melbourne (http://www.unimelb.edu.au/) was established in 1853 not long after the University of Sydney and the first four professors began classes in 1855. The medical school established in 1862 is the oldest school in Australia (this is just 30 years after the first settlement of Caucasians in the State). Its first professor was the eminent physiologist George Britton Halford, Professor of General Anatomy, Physiology and Pathology. For many years the department had strong interests in neurology and physical anthropology, which was not unlike the University of Sydney. However, at least at the University of Sydney, a separate department of Histology and Embryology existed where interests in development could be fostered. In 1928, C.W. Stump was appointed the Bosch chair of Histology and Embryology at University of Sydney and a separate department existed between 1956 and 1993. John Laverack was not appointed Reader in Histology and Embryology until 1956. Research in embryology or developmental biology was not strong in the Faculty of Medicine at the University of Melbourne and it was not until the appointment of Ian Darian Smith as Professor of Anatomy in 1983 that he began to slowly recruit people with an interest in the field.

Although not one of the oldest universities, the University of Queensland (http://www.uq.edu.au/) was established in 1910 - 20 years after University of Tasmania (1890) and 36 years after University of Adelaide (1874). It has quickly established itself as one of the premier higher education institutions in Australia. Despite the formation of a Faculty of Medicine in 1935 there has been little history of research strength in developmental biology within the University until more recently. Only in the last 10 years has a critical mass in developmental biology emerged, leading to the establishment of an independent stream of study of developmental biology in the Bachelor of Science degree in 2000. Research in this area has flourished since the establishment of the Australian Research Council Special Research Centre in Functional and Applied Genomics and its incorporation in the new Institute of Molecular Biology (see Fig. 2 and article by John Mattick, pp. YY in this edition).

Funding of Higher Education Research

In 1997, Australia had 42 public and three private higher education institutions. Of the 5.3 million people between the ages of 15-64, 660,000 are enrolled in undergraduate and postgraduate courses; 21% of these are in postgraduate courses.

The funding of Australia's higher education institutions is administered by the Higher Education Division of the Commonwealth Department of Education, Science and Training (http://www.detya.gov.au/). The funding group within this division is responsible for policies regarding funding for higher education and administers the Research Training Scheme, Institutional Grants Scheme and the Research Infrastructure Block Grants. Of particular importance to our research students this group also administers the Australian Postgraduate Awards and the Higher Education Contribution Scheme (a scheme introduced in 1989 to assist in partial recovery of costs from students).

The Commonwealth provides a block operating grant for each of 39 public education institutions. The amount allocated is determined on the basis of the teaching commitment of each institution. In 2001 this operating grant was $4.4 billion with the top three institutes being University of Sydney ($244 million), Monash University ($228 million) and University of Queensland ($219 million). An allocation for research is provided separately via the Institutional Grants Scheme (new in 2002, replaces the Research Quantum), the Research Training scheme and the Research Infrastructure Block Grants Scheme. The Institutional Grants Scheme provides monies for the research activities of Universities and allows these institutes considerable flexibility with respect to the way this money is directed into research activities. Funding is determined on the basis of a formula according to the number of research students (30%), research income (60%) and its research publications (10%). In 2001 the earlier version of this scheme – the Research Quantum -was $228 million with the top three institutions being University of Melbourne ($26 million), University of Sydney ($24 million) and University of Queensland ($23 million). The Insitutional Grants Scheme in 2002 will also incorporate the previous Small Grants Scheme which in 2001 was allocated $29 million.

The Research Training Scheme provides institutions with funds on the basis of number of higher degree completions (50%), research income (40%) and research publications (10%) for distribution as exemptions for students from contributing to the Higher Education Contribution Scheme. In 2001 the allocation was $505 million with the top three institutions being University of Melbourne ($54 million), University of Sydney ($53 million) and University of Queensland ($48 million). The Research Infrastructure Block Grants Scheme provides financial support according to the extent of competitively awarded research income. This money is specifically earmarked for assisting in the infrastructural support of research projects funded by Commonwealth funded projects. In 2001 the allocation was $82 million with the top three funded institutions being University of Melbourne ($10.7 million), University of Sydney ($9.4 million) and University of New South Wales ($8.9 million). In addition the Commonwealth also funds postgraduate student scholarships through the Australian Postgraduate Awards ($83 million in 2001) and the International Postgraduate Research Scholarships $17 million in 2001).

Competitive Research Programmes in Developmental Biology

Research activities of individuals and research teams are also supported by the Australian Research Council (ARC), which in 2001 was allocated $248 million. The ARC is responsible for advising the government on the distribution of research funding

through the National Competitive Grants Programme. The council has a full-time chief executive officer and six executive directors responsible for funding across six broad disciplines. Each executive director is advised by an expert advisory committee, which in turn is supported by discipline-specific readers. These readers provide expert advice with respect to assessment and ranking of project applications in their discipline. Proposals for developmental biology discovery grants are reviewed by the "Biological Sciences and Biotechnology" discipline panel consisting of nine Professors representing a vast majority of Australia.

The ARC provided support for 717 discovery projects which totaled $53 million in 2002. The mean first year grant in 2002 was $74,000 across all disciplines. In 2002 there were 12 new grants in the field of Development Biology (average grant size was $98,000). These grants were awarded to researchers in: the University of Queensland (four), Australian National University (three), University of Melbourne (two), University of Tasmania (one), James Cook University (one) and the Victor Chang Cardiac Research Institute (one).

In addition to discovery grants the ARC also awarded in 462 new linkage grants ($26 million; average first year grant was $55,000) in 2002 for collaborative research projects between university and industry; as well as 61 infrastructure projects ($25 million) for acquisition of equipment and facilities. There were five new linkage grants in 2002 in the field of Developmental Biology (average first year grant was $65,000) from the following institutions: Monash University (three), Australian National University (one) and University of Adelaide (one).

The ARC also supports Special Research Centres that enable high quality research of strategic advantage to Australia to be funded for up to nine years. In 2001, 19 centres were funded by the ARC ($15 million) including two centres concerned with Developmental Biology: the Centre for Functional and Applied Genomics ($1 million) at the University of Queensland (see profile in this edition) and the Centre for Molecular Genetics of Development ($1 million) at the University of Adelaide.

In addition to the ARC, the National Health and Medical Research Council (NH&MRC) (http://www.health.gov.au/hfs/nhmrc/) is another major source of funds for researchers in the field of Developmental Biology. The Research Committee of the NH&MRC is responsible for funding individual researchers or team projects, broad programmes of research, fellowships and special units via a rigorous peer-reviewed process. The NH&MRC obtains financial support from the Medical Research Endowment Reserve which was specifically established by the Commonwealth to fund medical research. Unlike the ARC which funds researchers who are only employed principally by a higher education institution the NH&MRC research funding is open to individuals outside of the higher education sector including government departments and hospitals, as well as private institutions and organizations. Funds are available for research projects, for programs to support large groups of researchers, and for institutes. In addition NH&MRC supports training fellowships for graduates and training scholarships for students undertaking higher degree studies in both health and medical research. Project grants are typically awarded for three years and in 2001 459 new projects were funded ($47 million). A vast majority of new project grants (76%) in 2001 were awarded to Victoria (34%), New South Wales (28%) and Queensland (14%). In 2001 the top three institutes for project grants were University of Melbourne (14%), University of Sydney (13%), and University of Queensland (11%).

NH&MRC funded 12 new projects grants ($1.4 million) and one new fellowship grant ($185,000) in developmental biology in 2001. A majority of grants were awarded to researchers at two insititutes: University of Queensland (five grants) and University of Melbourne (four grants). It is clear that both in the number and the average size of project grants that the NH&MRC seems to be directly funding more developmental biology studies than the ARC. The average grant size from ARC was $65,000 whereas from NH&MRC it was $116,000. However, these figures can be somewhat misleading since as noted above ARC also indirectly supports higher education researchers with infrastructural funds, institutional funds as well as with student awards and HECS exemptions. NH&MRC also supplies the University with overhead supplements but this is much less than that provided by the ARC. Moreover, the NH&MRC grants can sometimes appear larger because they can include salaries for the chief investigator whereas those from ARC do not (ARC chief investigators must be supported financially by a higher education institute).

While these figures seem surprisingly low in comparison to average grant sizes in other countries such as the United States of America, it should be remembered that these grants do not include overheads and in many cases do not include the chief investigator salary. However, even taking this into account there is a clear discrepancy in the levels of funding between Australian researchers in developmental biology and their international colleagues. While it easy to highlight this anomaly it is just as easy to defend it on the basis of sheer availability of resources. It is pertinent to point out that the population of Australia at 19 million is distributed across a continent that is very similar in size to that of the mainland United States of America with its population of approximately 240 million. Interestingly for further comparison, the population of New York city and its boroughs at 16 million is not far different from the whole of Australia.

State Profiles on Developmental Biology

Developmental Biology in Western Australia

The research interests of groups in the domain of developmental biology cover areas of tissue formation, repair and stem cells, especially with respect to skeletal and cardiac muscle (Miranda Grounds, Marie Bogoyevitch, Jason White, Nadia Rosenthal, Mel Ziman), Neuroscience (Alan Harvey, Giles Plant, Sarah Dunlop, Lyn Beazley) and the eye (Piroska Rakoczy). These groups are located mainly at the University of Western Australia, and also at the Lions Eye Institute and Edith Cowan University. A strong interest in the role of cell-matrix interactions in developmental processes, especially in developing and regenerating muscle, forms the basis for collaborative research with Lydia Sorokin and her colleagues.

Developmental Biology in South Australia

South Australia has long history of research in developmental biology, mostly centred around the University of Adelaide. This was recognised in 2000 when the Australian Research Council together with the university created the Special Research Centre for the Molecular Genetics of Development (CMGD). This centre shares space and personnel with the Department of Molecular

Biosciences in the Molecular Life Sciences building – a purpose-built laboratory facility completed in October 2000. The CMGD provides long-term funding for a number of postdoctoral fellows and students, as well as organizing visits from national and foreign researchers and workshops in developmental biology. It currently hosts the best collection of model organisms in Australia with state-of-the-art facilities for research in chick, *Drosophila*, mouse, zebrafish and yeast. The CMGD benefits from access to in-house microarraying and monoclonal antibody production facilities.

Adelaide is best known internationally for its research into *Drosophila* development and mouse embryonic stem cell differentiation. Professor Robert Saint who headed the *Drosophila* effort has recently moved to Canberra. As a consequence, the CMGD has been expanded to cover his laboratory at the Australian National University (ANU). This promises to promote greater exchange between researchers in Adelaide and The Research School of Biological Sciences at the ANU. The work of Professor Peter Rathjen on control of mouse embryonic stem cell differentiation is currently being commercialised by BresaGen, a multinational biotechnology company that began life at the University of Adelaide. Other research groups include those of Tim Cox (inherited craniofacial abnormalities in humans and mice), Stephen Dalton (cell cycle control in yeast and mammalian stem cells), Simon Koblar (Eph/ephrin signalling in chick neural development), Michael Lardelli (neural and somitic development in zebrafish), Robert Richards, (*Drosophila* models of neural degenerative diseases), Elizabeth Runciman (Flinders University - neural development in wallaby), Robert Rush (Flinders University – neurotrophins), Murray Whitelaw (mammalian *sim* gene function) and Stephen Wood (ubiquitin action during mouse development).

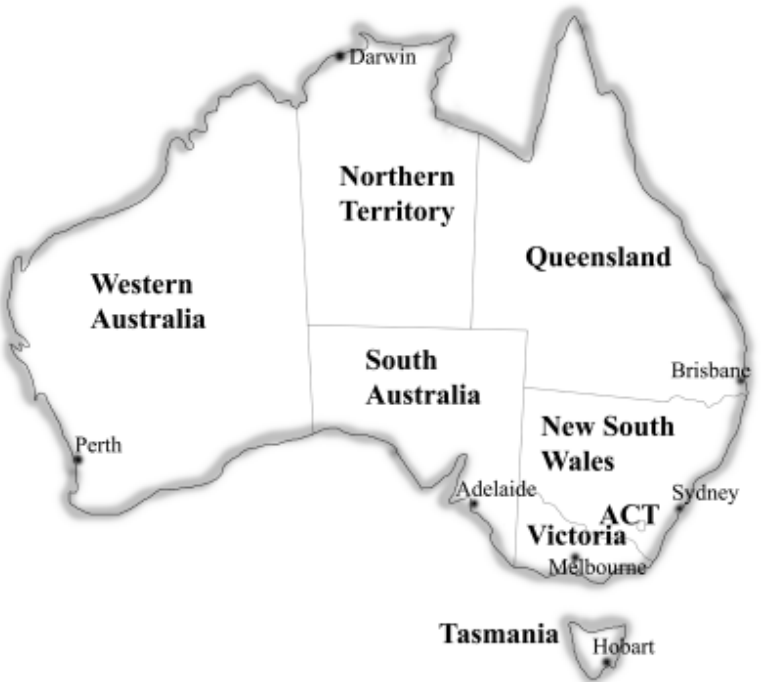

Fig. 1. Map of Australia detailing the six states and two territories as well as the major capital cities. *Not shown is Canberra which is the capital of the Australian Capital Territory (ACT).*

A number of other groups in Adelaide work at the interface between developmental biology and other disciplines. Of special note is work headed by Professor Caroline McMillen, Associate Professor Julie Owens and Professor Jeffrey Robinson in the Centre for Physiology of Early Development at The University of Adelaide. These scientists are investigating the effects on adult physiology of challenges to fetal development using, primarily, the sheep as a model.

Developmental Biology in Victoria

Victoria has a rich history of research in developmental biology in both its Universities and its many high profile research institutes. At the University of Melbourne developmental biology is centred around the Department of Anatomy and Cell Biology which houses the groups of Gary Hime and Miriam Ford. Gary Hime's group works with *Drosophila melanogaster* as a model to dissect the functions of the *Cbl* proto-oncogene and *Patched* tumour suppressor gene. He also uses the *Drosophila* testis as a genetically manipulable model of stem cell regeneration and differentiation. Miriam Ford's group is interested in the regulation of FGF signalling in the developing mouse brain. Her laboratory has a particular focus on the role of heparan sulfate proteoglycans (HSPGs) which are essential co-receptors in the creation of an active FGF:HS: FGF receptor signalling complex. Eleanor Mackie at the School of Veterinary Science studies the role of the extracellular matrix in skeletal development. Monash University, on the other side of Melbourne, has groups interested in the molecular genetics of flower development (David Symth, School of Biological Sciences), differentiation in cells of the testis (Kate Loveland, Monash Medical Centre), and transcriptional regulation of mesoderm patterning and programming (Andrew Perkins, School of Biomedical Sciences). Deakin University is home to the Alistar Ward's group that is investigating the genes responsible for leukaemia development using a novel genetic approach in zebrafish. Jenny Graves at LaTrobe University has a research group with a uniquely Australian flavour, focusing on Australian animals. She has made use of the natural variation between distantly related species like humans, mice, kangaroos and platypus - and now emus and snakes - to work out how and why genes and chromosomes of mammals have changed during the last 200 million years of mammal evolution. Her work has delivered some big surprises about how sex is determined in all mammals, and how sex chromosomes and the genes on them evolved.

In addition to the major Universities there are numerous groups scattered throughout the research institutes with major interests in developmental biology including Lorraine Robb (the Walter and Eliza Hall Institute of Medical Research in Melbourne) who is concentrating on the specification of haematopoietic progenitor cells in the early murine embryo; Helen Abud (Ludwig Institute for Cancer Research) who is studying the patterning and development of the gut using the mouse as a model; Paul Thomas (Pituitary Research Unit, Murdoch Children's Research Institute) who investigates the genetic programme that controls progenitor cell commitment and differentiation during pituitary organogenesis; and

Don Newgreen (Murdoch Children's Research Institute Research) has a long established group which is internationally recognized for his work in embryology, using cell biological models and whatever molecular techniques he can lay his hands on. There are several groups active in developmental biology at the Ludwig Institute for Cancer Research in Melbourne. There is a particular interest in this field at this institute because of the frequent correlation between those genes dysregulated in oncogenesis and those that are developmentally important in organogenesis. The Cytokine Biology Laboratory (Graham Lieschke, Head) focuses on developmental haematology and the genetic control of haematopoietic stem cell fating. The Colon Molecular and Cell Biology Laboratory (Joan Heath and Matthias Ernst, Joint Heads) pursues questions of gut development and intestinal organogenesis. As well as an extensive program based on murine models and targeted gene modification, the institute has made a considerable commitment to zebrafish as a genetically tractable model with an embryology conducive to these studies.

Developmental Biology in New South Wales

Developmental Biology in NSW is a growing concern. Our Universities and Research Institutes are populated with enthusiastic researchers keen to explore the complexities of embryonic development. The main centres for research are on the east coast, each being separated by some 200 kilometres. The largest, Sydney, is flanked by Newcastle to the north and Wollongong to the south. Not surprisingly Sydney (the state's capital) is home to the greatest number of researchers and thus the most developmental biologists. Within Sydney the Victor Chang Cardiac Research Institute (VCCRI) and the Children's Medical Research Institute (CMRI) represent two of the largest centres of research into developmental biology. The VCCRI represents a rapidly growing centre for developmental biology having recruited the head of the Developmental Biology Unit, Professor Richard Harvey, and laboratory head, Dr Sally Dunwoodie, within the last four years. Their mouse-centric work is soon to be complemented by the recruitment of Dr Peter Currie, an Australian returning home after some 15 years in the USA and United Kingdom. Dr Currie promises to make a splash as he imports his research interests and zebrafish from the MRC in Edinburgh. Research at the VCCRI focuses on cardiovascular and muscle development, however, topics such as evolution of the limb and skeletal development are also examined. At the CMRI, Professor Patrick Tam runs a very productive Embryology Unit with diverse interests that include embryonic patterning, craniofacial and limb development, and gene imprinting. The Developmental Neurobiology Unit is run by Dr Peter Jeffrey, and the Muscle Development Unit headed by Dr Edna Hardeman focuses on the use of transgenic mice to understand the role of specific molecular components in muscle function.

In order to foster communication and collaboration within this growing scene the NSW Cell and Developmental Biology Group was established in 2000 by Professor Peter Gunning (the Children's Hospital at Westmead), Drs Edna Hardeman and Patrick Tam (both from the CMRI). This group meets twice a year at different research locations and enjoys presentations by students, postdoctoral scientist and group leaders representing a diverse set of interests. A non-profit organization (Hunter Cell Biology Inc) formed by scientists who previously organized a successful International Congress on Cellular and Developmental Biology in Queensland in 2000, the year of the Sydney Olympic Games has hosted in 2001 the First Hunter Valley Cellular Biology Meeting, which has now evolved into an annual event. The Hunter Valley is a major wine-growing region in Australia and is a perfect the venue a meeting that allows researchers, for two days, to focus on trafficking, secretion, stem cell biology and embryonic development in a collegial environment. The major goal of the meeting is to encourage interaction with invited international speakers and hopefully stimulate scientific collaborations locally and internationally.

Developmental Biology in the Australian Capital Territory

Developmental biology in the territory is presently in a period of transition, with several major new initiatives just getting well launched at the Australian National University. Two of these are the Medical Genome Centre and the Australian Phenomics Centre in the John Curtin School of Medical Research (JCSMR), both headed by Professor Chris Goodnow, and both studying the mouse with the goal of understanding the roles of genes and the proteins that they encode. Many mutagenised genes will show their effects during development, so inevitably a great deal of developmental biology will be done in these facilities. In addition to the genome wide mutagenesis approach taken in the Medical Genome Centre several other researchers in the JCSMR are using the more traditional approach of targeting specific genes in the mouse, which again may show their effects during development.

Professor Robert Saint has recently joined the Research School of Biological Sciences at the Australian National University. He comes from the University of Adelaide to take up the position of head of the Molecular Genetics and Evolution Group. He has also kept his position as Director, Centre for the Molecular Genetics of Development, which will serve to increase interactions between developmental biologists in Canberra and Adelaide. His arrival will increase the diversity of developmental research within RSBS, which now includes corals, grasshoppers, fruit-flies, honeybees, marsupials and mice. This diversity of organisms also involves a diversity of interests and approaches spanning evo-devo, functional genomics, learning, establishment and function of the nervous system in early development, and the function of specific genes.

At the Australian National University's Research School of Biological Sciences, the Plant Cell Biology Group studies the cellular and molecular basis of plant growth and development. Their research focuses on determining the mechanisms that regulate cell division, cell expansion and the interaction of plants with fungal pathogens and their responses to signals from the environment. In 2001, Geoffrey Wasteneys and his colleagues reported their discovery of MOR1, a microtubule associated protein that controls cell morphogenesis throughout plant development. The *MOR1* gene is a member of a recently discovered family of proteins including the human TOGp and *Xenopus* XMAP215. Although MOR1 is essential for the controlled expansion of plant cells, it probably also plays a vital role in cell division. Occurring as a single copy gene in *Arabidopsis thaliana*, but possessing 52 introns, alternative splicing could provide specialized isoforms.

At Plant Industry (Commonwealth Scientific and Industrial Research Organization), Jean Finnegan and her associates are looking at the role of DNA methylation and, more recently, at chromatin remodelling on plant development. Their work focuses specifically on the vernalization response and, in collaboration with Abed Chaudhury's group, on seed development. Chaudhury and his coworkers are looking at factors that regulate embryo and

Fig. 2. The Institute of Molecular Biology, Brisbane, under construction. *The University of Queensland, Queensland State government and the Australian government have made a large investment in developmental biology through the construction of the Institute of Molecular Biology on the Brisbane campus of the University of Queensland. What began as a hole in the ground in March 2001* **(A)** *is now taking shape in March 2002* **(B)** *as Australia's newest biomedical institute.*

endosperm development. Frank Gubler and his research group are working on seed germination, specifically investigating the role of the hormones ABA and gibberellin in regulating dormancy and mobilization of endosperm reserves. Cotton fibre development is the focus of a research team led by Danny Llewellyn.

Developmental Biology in Queensland

The construction of a new institute – the Institute of Molecular Bioscience – at the University of Queensland (Fig. 2) is stimulating a lot of excitement in the field of developmental biology in Queensland. Already Queensland has seen several major groups move from Victoria in the last 10 years to take up positions within the Department of Anatomy and Developmental Biology (Fig. 3) at the University of Queensland (Julie Campbell, Gordon Campbell, Victor Nurcombe, Brian Key and James St. John). There is a strong push to concentrate developmental biology in this hub – especially as the Australia's only University developmental biology department is located adjacent to the new institute. This institute is home to the Centre of Functional and Applied Genomics which is the subject of a separate profile by John Mattick, pp. XX in this special edition. There are also other strong groups in developmental biology at the University of Queensland including those led by Peter Noakes (Department of Physiology and Pharmacology), David Merritt (Department of Zoology and Entomology), Bernie Degnan (Department of Zoology and Entomology) and Joseph Rothnagel (Department of Biochemistry and Molecular Biology). Andrew Boyd, also originally from Melbourne, has established a laboratory interested in developmental patterning at the Queensland Institute of Medical Research.

Peter Koopman from the Institute of Molecular Biology co-ordinates the Brisbane Developmental Biology Seminar Series which is supported by the Institute, the Faculty of Biological and Chemical Sciences and by industry. Each month the developmental biology community comes together for a seminar by either a local speaker, or a visiting international scientist or an interstate guest. The supply of pizza and beer that accompanies the seminar provides a stimulating environment and certainly enhances the discussion and atmosphere of the occasion.

Teaching of Developmental Biology in Australia

Western Australia

Within the University of Western Australia (WA), a new Developmental Biology course has been established. This advanced intensive 3rd year course will focus on understanding the molecular mechanisms of Developmental Biology (see http://www.anhb.uwa.edu.au/). The main themes are the molecular basis of axis development and pattern formation (cell differentiation and morphogenesis) and organogenesis; examples from *Drosophila*, *Xenopus* and mouse are used to present the basic concepts. The first course will run as a 3rd semester unit in 2002 and will be held over 6 weeks during January/February 2003. It will be run by Lydia Sorokin and Rupert Hallmann from Lund (Sweden) who have strong connections with Western Australia. The final week will consist of a workshop with international and interstate participants.

This teaching initiative and the local Workshop complements other local developmental/molecular biology activities related to Nadia Rosenthal, who is the first Professor-at-Large (Institute of Advanced Studies) at the University of Western Australia (http://www.ias.uwa.edu.au/). Nadia Rosenthal has recently taken up a position as Coordinator of the EMBL Programme in Mouse Biology, at Monterotondo in Italy (she was previously based in Boston, USA). These very strong international contributions to the local combined teaching and research activities provide a firm base to rapidly expand the discipline of Developmental Biology within Western Australia and to build collaborations with other Australian and international researchers.

South Australia

At Adelaide University there is a second year course entitled "Cells, Tissues and Development" for Bachelor of Health Science students that is coordinated by Julie Haynes (julie.haynes@adelaide.edu.au). The overall aims are: (1) to study the microscopic structure of the major organs and systems of the human body; (2) to understand the structure-function relationships of cells and tissues in the major organs; and (3) to study early embryonic development and to be introduced to selected topics in

reproductive biology. There are also two third year courses entitled "Structural Cell Biology" (coordinated by Jeff Trahair) and "Comparative Reproductive Biology of Mammals" (co-ordinated by Bill Breed; bill.breed@adelaide.edu.au). The latter course mainly focuses on the cell biology of eggs and sperm with information on development of the early mammalian conceptus covered only rather superficially.

Michael Lardelli (michael.lardelli@adelaide.edu.au) has been instrumental in the second and third year teaching of developmental biology in the genetics division of the Department of Molecular Biosciences. In second year, mutation screens, genetic analysis of *Drosophila* segmentation and *Arabidopsis* flower development are covered. In third year, more specific topics such as development of the olfactory system including transgenic analysis in mice, *Notch* gene function and vertebrate segmentation concentrating on zebrafish are discussed.

Victoria

Deakin University: Leigh Ackland (leigha@deakin.edu.au) from the Centre for Cellular and Molecular Biology teaches a third year unit called "Cell and System Physiology" which has several weeks of lectures on developmental biology.

University of Melbourne: There is a third year course named "Developmental Biology" which is jointly co-ordinated between the Departments of Zoology (Marilyn Renfree) and Anatomy and Cell Biology (Gary Hime). Topics covered in the course include: mechanisms of cell determination and commitment; embryonic organizer mesoderm induction; establishment of the invertebrate and vertebrate body plan; positional specification and tissue patterning; epithelial-mesenchymal interactions; sex determination; developmental potency; growth control; ageing and senescence; evolution and development. The course consists of 24 lectures and 24 hours of practical classes. The practicals included: observation of cleavage in ascidian and zebrafish embryos; immunostaining of *Drosophila* embryos with an antibody directed against the engrailed segment polarity protein. The main practical project runs over several weeks and involves an examination of early stages of chick development and practice with manipulating the chick embryo. After the students gained some confidence with working with chick embryos we got them to implant beads coated with bFGF. After culture for another week the students looked for evidence of developmental abnormalities, particularly ectopic limbs. Helen Abud planned and taught this practical with Gary Hime. Problem based learning exercises on identification of developmental genes, induction and competence of embryonic tissues, cell signalling pathways in development and disease are also part of the course.

Andrew Sinclair from the Department of Paediatrics runs an advanced course on "Molecular Biology of Human Development and Disease" which consists of 15 two-hour lectures. The course is designed to provide an introduction to biomedical research; foster the development of research skills and allow students to develop a line of research through hypothesis testing, experimental design and practical experimentation; develop oral and written communication skills; encourage the development of independent thinking and critical analysis of the scientific literature; and enhance the understanding of the broader areas of contemporary biomedical science.

Monash University: David Symth (david.smyth@sci.monash.edu.au) co-ordinators a third year subject called "Genetics of Development"

Fig. 3. Australia's only Department of Anatomy and Developmental Biology (A) *is situated in the heart of the University of Queensland next to the new Institute of Molecular Biology. The refurbishment of this building began in 2000, commissioned by the Dean of the Faculty of Biological and Chemical Sciences, Professor M. McManus. This initiative strengthens the University of Queensland's commitment to Developmental Biology. The 6th floor of the building has purpose-built molecular biology laboratories* **(B)** *for developmental groups including tissue culture, time-lapse image analysis and zebrafish/Xenopus egg injection rooms.*

within the Bachelor of Science degree, which was taught for the first time in 2001 to a class of 67 students. It includes 24 lectures; a series of three practical exercises each over three weeks (*Arabidopsis* flower development, body plan genes in *Drosophila*, and effects of growth factors in chick development); a series of student oral presentations on topical issues in developmental biology (cloning, stem cells, transgenic foods, genome projects, congenital abnormalities, and gene patenting); and an essay on recent advances in our understanding of the genetic control of organogenesis for one organ system in humans (either eye, tooth, digit, kidney, heart, or mid-brain). The text is Wolpert's "Principles of Development" together with the new sixth edition of Gilbert's " Developmental Biology" as a reference backup.

New South Wales

University of Sydney: The "Cells and Development" course is run in 3rd year in the Department of Anatomy and Histology and is co-ordinatored by Frank Lovicu (lovicu@anatomy.usyd.edu.au) and John McAvoy (johnm@eye.usyd.edu.au). In this course the major questions in animal development are covered, including: "How does a single cell give rise to the diverse cell types of the adult body?" and "How do different tissues arise in the embryo and come together to form organs and organ systems?" The course consists of the following main sections: (1) beginning a new organism - includes oogenesis (two lectures) and fertilization (two lectures); (2) multicellularity - includes cleavage (two lectures) and gastrulation (two lectures); (3) formation of the primary germ layers and organogenesis - includes formation of tissues and organs arising from ectoderm, mesoderm and endoderm (nine lectures) and stem cells (three lectures); and (4) mechanisms of differentiation and morphogenesis - includes differential gene expression (16 lectures) and cell and tissue interactions (12 lectures). In both lectures and practicals a broad approach is taken to the study of developmental mechanisms. This includes the approaches of molecular, cellular, histological and embryological disciplines.

University of New South Wales: Mark Hill (m.hill@unsw.edu.au) teaches "Embryology" to medical students as a component of their first and second years. In addition Science students have available two courses entitled "Vertebrate Development A" and "Vertebrate Development B". In addition some aspects of development are taught in the "Cell Biology" course. Both medical and science students use the computer program "UNSW Embryology" (available both on the Web and on compact disc) in practical classes and tutorials. Practical classes involve working through a series of images, figures, research images, movies, histology images and serial sections to investigate how early development and systemic development normally occur and related developmental abnormalities. More recently, concepts in the molecular basis of normal/abnormal development have also been discussed. Medical students are also set at the end of each practical class a series of self-tutorial clinically related questions. Lecture slides and additional notes are also made available for viewing, downloading or printing in pdf format or as a web powerpoint presentation (http://anatomy.med.unsw.edu.au/cbl/embryo/embryo.htm)

Queensland

Griffith University: Derek Kennedy (D.Kennedy@imb.uq.edu.au) organizes a course "Gene Expression and Development" for about 30 students which is delivered over the second semester of the third year for Science students and is covered in 21 lectures. In addition to lectures from Derek there is usually use one other internal lecturer (three lectures) and an external lecturer (Joe Bowles from University of Queensland) who delivered an additional three lectures in 2001. The course is based around "Principles of Development" by Wolpert and "Developmental Biology" by Gilbert and covers topics such as: mechanisms of transcription; developmental control of transcription; genes controlling sex determination in *Drosophila*, *Caenorhabditis elegans* and humans; *Drosophila* development; and limb bud development in vertebrates. The pre-requisites for this subject are "Molecular Genetics" (a second year subject) and "Molecular Biology" (first semester of third year). "Gene Expression and Development" is an elite subject for students wanting to see living organisms from both a reductionalist and systems viewpoint. The students need to be familiar with all their undergraduate subjects to see how all the cellular functions can be orchestrated to make a new organism. A high percentage of students that do the subject continue to do a higher degree.

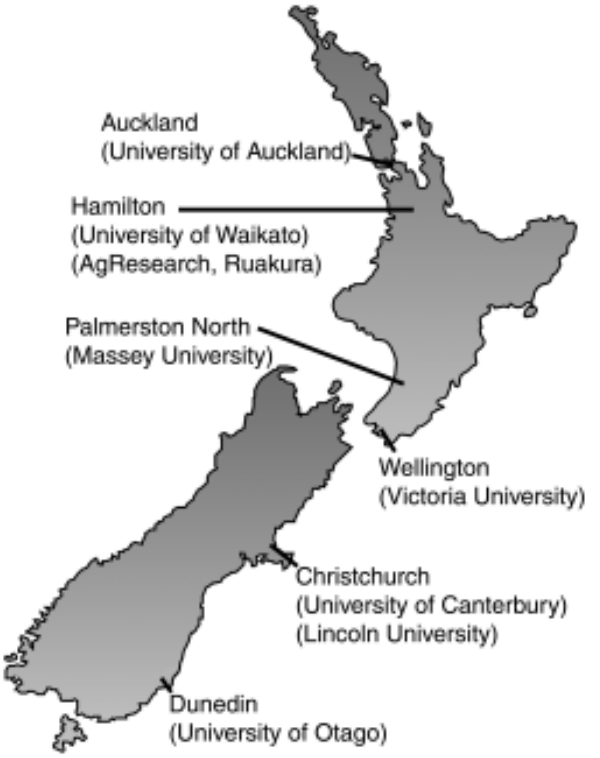

Fig. 4. Map of New Zealand showing the location of the major institutes undertaking research in developmental biology.

University of Queensland: The University of Queensland has a specific major of "Developmental Biology" in their Bachelor of Science degree which is co-ordinated by Victor Nurcombe (Department of Anatomy & Developmental Biology). The major is centred around three core courses that involve many lecturers from across the Faculty of Biological and Chemical Sciences as well as researchers from the Institute of Molecular Bioscience. In second semester of second year Victor Nurcombe co-ordinates the developmental biology portion of the course "Cell and Developmental Biology". This course is concerned with advanced cellular functions and behaviours and how these shape animal/human devel-

opment. Cutting edge technologies that have yielded these insights are emphasised, particularly in regard to biomedicine. Topics addressed include: cell-cell signaling and morphogens; cell-matrix and adhesion; the cell cycle/apoptosis/senescence/ stem cells; oogenesis and the compartmentation of maternal information/fertilization and the mechanisms of cleavage; cell lineage analyses/fate maps/inductive processes, including morphogen gradients; the role of epithelial-mesenchymal interaction and transition in differentiation and morphogenesis; the mechanisms of gastrulation and axis specification; organogenesis, including the central and peripheral nervous systems, the limbs, the kidneys and the gonads; the relationship between development, genes and evolution and the modern genetic and cellular methods used to understand the mechanisms of development. The course has three lectures a week for 13 weeks as well as five wet based practicals. Practical classes concentrate on basic procedures in handling and manipulating cellular and embryological material. The set text for the developmental biology component is Gilbert's "Developmental Biology". Wolpert's "Principles of Development" is also recommended as are Gilbert and Raunio's "Embryology. Constructing the Organism" and Slack's "From Egg to Embryo. Regional Specification in Early Development".

In third year, students majoring in developmental biology take a first semester course called "Developmental Neurobiology" co-ordinated by Brian Key (Department of Anatomy and Developmental Biology). This course consists of 36 lectures and 12 web based tutorials. Subject matter is centred on the basic principles of development of nervous systems: induction, regional specification, neurogenesis, gliogenesis, differentiation, plasticity, cell death, axon growth and guidance. The significance of understanding development for facilitating regeneration and recovery of function following disease and injury is highlighted. The overall goal of this course is to appreciate and understand the major questions facing the field of developmental neurobiology especially in relation to biomedical science. A major focus will be on the approaches and strategies necessary to address these questions. The set text is "Development of the Nervous System" by Sanes, Reh and Harris.

In second semester of third year, Victor Nurcombe co-ordinates a course on "Molecular Mechanisms of Development". This course covers the cell biology and genetic regulation of animal and human development and includes evolution, embryonic pattern formation, cell and tissue growth, and how concepts from these are informing the attempts to use stem cells for tissue engineering in biomedicine. The course focuses on how modes and varieties of molecular expression guide cell and tissue morphogenesis during the development of both invertebrates and vertebrates. An overview of how this understanding is shaping modern medicine and animal husbandry is provided; this in turn illustrates just how fundamental Developmental Biology has been to the whole biotechnological revolution. There are 36 lectures and 12 computer practicals. The set text is Gilbert's "Developmental Biology".

Developmental Biology in New Zealand

New Zealand became geographically isolated from the remainder of the world prior to the evolution of snakes, mammals and various classes of plants. The first terrestrial mammal to enter its islands was man, with even this being a comparatively recent event. The first settlers, the Maori, arrived from Polynesia in the 10th century and become established by the 12th century. European discovery of New Zealand dates from 1642, with colonisation beginning in the 1840s, under the jurisdiction of New South Wales. British colonisation was initially formalised by the Treaty of Waitangi and then extended by land wars. After an extended period in which the Treaty of Waitangi was not ratified, it has become one of the founding statutes of the nation.

New Zealand was the first universal democracy. Universal suffrage for men, irrespective of land ownership or race, dates from 1890, with all women obtaining the vote three years later. When first established in 1852, the national government had a General Assembly and six provincial governments, which were subsequently abolished in 1876.

Despite it origins as a dependency of an Australian state, New Zealand elected to remain outside of the Australian Federation. However, a very close co-operation exists between the two nations, which in some areas is increasing. This is particularly true in Science, with most New Zealand scientists being members of Australian or joint Australian/ New Zealand societies.

The population of New Zealand is 3.7 million (http://www.stats.govt.nz/). Although its economy is based on agriculture, 85% of New Zealand's population is in urban centres. The largest of these are Auckland (1,100,000), Wellington (340,00), Christchurch (340,000), Hamilton (166,00) and Dunedin (110,000).

The two most notable Universities in New Zealand are the University of Otago, situated in Dunedin, and the University of Auckland. The University of Otago (http://www.otago.ac.nz/) is New Zealand's oldest tertiary institute (Fig. 5), having been established in 1869, a mere 21 years after the first settlers arrived from Scotland. In the 1860's Dunedin was New Zealand's largest city with a population of 60,000. Its economy was based on gold and its future appeared to be as a port of international significance, being the closest Pacific landfall to South America. With the development of stream-driven ships and the opening of the Panama canal, Dunedin metamorphosed from a commercial centre to the nation's premium education and research centre. At the last census (1998), 20,600 of its 110,000 citizens were tertiary

Fig. 5. One of the foundation buildings of the University of Otago. *Construction began on this building in 1869, although its current form dates from the early 20th century. Today, this building houses the University's registry.*

Fig. 6. (Left) Otago museum, *the site of the some of the earliest developmental biology studies in New Zealand. Built in 1877.*

Fig. 7. (Right) The Lindo Ferguson Building. *This building was completed in 1925 and is one of oldest remaining buildings of the University of Otago Medical School. The earliest studies in New Zealand of human development and the cellular aspects of animal development were undertaken in this building.*

students (http://www.stats.govt.nz). The Anatomy museum in the University contains a small but impressive collection of human concepti from the 1800s. This suggests that embryology teaching began with the introduction of medicine to the University in 1875. Human embryology has been a prominent part of the teaching of medical topographic anatomy, until the middle 1990s. Today, the main preserve of developmental biology teaching is in the science courses offered by the Departments of Anatomy and Structural Biology and Zoology. These courses are multi-disciplinary, with the molecular and cellular aspects of development being integrated with the teaching of developmental anatomy. From this year, students will be able to take Reproductive and Developmental Biology as their major subject for the first time in New Zealand.

The University of Auckland was founded in 1883, to train law clerks and teachers. During the 1900s substantial internal migration transformed Auckland into New Zealand's major city. The University has grown with the city, both in breadth of the subjects taught and in total size. The 1940s and 1960s were decades of major expansion. The introduction of a small medical school in 1968 has been particularly important in strengthening the biological sciences at Auckland. The University continues to grow, with student numbers having almost doubled in the last decade (http://www.auckland.ac.nz/).

Because of the geographic history of New Zealand, its ecology is remarkable and unique. The exploration of its flora and fauna was initially through regional museums. Joint appointments between museums and universities gave rise to the first departments of Zoology and Botany. Some of the earliest research in developmental biology was done in these Departments as part of the description and exploration of native plants and animals. Frederick Hutton (1836-1905) was one of the early curators of the Otago Museum (Fig. 6) as well as a lecturer at the University of Otago. In his time, he was regarded as the leading figure in developmental biology in New Zealand. His most lasting impact is, however, through his cataloguing of native species. Similarly, Thomas Parker (1850-1897), an early Professor of Biology at Otago, was elected to the Royal Society of London for his work recording the comparative anatomy and development of New Zealand's flightless birds.

Funding of Higher Education Research

Higher education is administered and funded in New Zealand by the Ministry of Education (www.minedu.govt.nz). In 1998, New Zealand had eight Universities, all of which are public, as well as various other tertiary institutes. 106,000 students were enrolled at these Universities, with the other institutions catering for another 150,000 tertiary students. 57% of New Zealanders leave the education system with a tertiary qualification (http://www.stats.govt.nz/).

Historically, universities have been funded on a per student basis by the government, with only minimal student fees. Different courses (medicine, science, humanities, etc) are funded at different levels, in recognition of their different costs. In 2001, Government funding of tertiary institutions was $NZ 1,346 million a year. In recent years, the level of student fees has increased markedly. These fees are paid directly to the universities and are not included in the above figure. Universities have been expected to support research from these sources of income, as well as providing infrastructural support for externally-funded research.

The mechanism of funding academic research is in a state of transition, with the Government moving to link the funding of research more directly to the research being undertaken. Through the 1990s, the Government began to move from marginal to full-cost funding of its research programmes (see below). In 2000, the research component of undergraduate student funding was decreased whereas the component for post-graduate study was increased. Consideration is being given to funding the various tertiary institutes differentially on the basis of the research output of their staff.

At present, the research monies provided to the universities nominally provide 20% of academic salaries, some infrastructural

support and sufficient funds for small projects. Academics undertaking research of international quality are almost totally dependent on external sources of funding for their research.

Competitive Research Programmes in Developmental Biology

Research in developmental biology in New Zealand is supported by the Government, through the Marsden Fund and the Health Research Council (HRC). Applications to these agencies are assessed by discipline-based committees. These committees are much broader than their overseas equivalents due to New Zealand's small size. Extensive use is, however, made of anonymous referees to ensure that only international quality research is funded.

The Marsden Fund supports curiosity driven research and is administered by The Royal Society of New Zealand (http://www.rsnz.govt.nz/). $NZ 28 (US$ 12.6) million per annum is split between science, social science and the humanities. In the last round, 73 of the 834 applications were funded, with 56% of the funds going to the medical and life sciences. The projects are funded for 3 years, with a typical award being in the region of $NZ 150,000 (US$ 67,500) per year. This includes overhead funding, which for Universities is at the level of 85% of the salary component. In the last 5 years, 12 awards have been made in the discipline of Developmental Biology. These grants were awarded to the University of Otago (six), AgResearch (one), the University of Auckland (one), Waikato University (one), Massey University (one) and HortResearch (one). The fund research topics are mainly cell biological studies, such as the control of skeletal muscle development, but also include projects on the branching patterns of plants and the development of memory in human infants. Although the monetary value of these awards is small by international standards, the Marsden Fund is much appreciated by New Zealand scientists. Its willingness to provide a portion of the academic salaries of successful applicants has a pivotal role in maintaining the strength of the basic sciences in New Zealand.

The HRC (http://www.hrc.govt.nz/) is the main agency for coordinating and funding health research. Their budget of $NZ 45 (US$ 20) million per year supports biomedical, clinical and public health research. Areas of research with specific relevance to New Zealand have been identified and are given priority for funding. However, scientific excellence is still a major criterion with the national importance of the research mainly affecting grants that are ranked at the margins for funding. Historically, the HRC and its predecessor, the Medical Research Council, funded most of developmental biology research in New Zealand. Its role in this area has diminished but not ceased. In the current regime, biomedical researchers are only funded if they provide a clear and relatively direct link between their research and a health-related problem. In the last two years, the HRC has funded research on the maintenance of pregnancy and the effects of hypoxia on human fetuses. No major grants on the cell biological aspect of development have been funded, although some funded projects have small sections within them devoted to this type of research. This, however, does not reflect the longer term picture. With small communities such as New Zealand, very large year-on-year fluctuations in areas of research funded are common. The HRC remains an important source of funds for developmental biologists.

Several smaller agencies exist for funding research, the most notably of which is the Lottery Grant Board. This agency is administered by the Department of Internal affairs (www.dia.govt.nz) and obtains its funds from the proceeds of a lottery. Its main function has been in the provision of short-term career support and equipment. It has recently ceased to fund general science but continues to support medical sciences at the level of $NZ 2.3 (US$ 1.04) million per year.

The main funding of research in New Zealand is through the Foundation for Research, Science and Technology (FRST) (http://www.FRST.govt.nz/). FRST supports research and science with economic, environmental or social benefits at a level of $NZ 400 (US$ 180) million per year. It occasionally funds developmental biology studies that are of direct commercial interest to one of the nation's agricultural industries.

KEY WORDS: *funding, history, universities, medical research*

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