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"... for the encouragement of studies and investigations in Science Art Literature and Philosophy ..."

THE ROYAL SOCIETY OF NEW SOUTH WALES

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The Society traces its origin to the *Philosophical Society of Australasia* founded in Sydney in 1821. The Society exists for "*the encouragement of studies and investigations in Science Art Literature and Philosophy*": publishing results of scientific investigations in its *Journal and Proceedings*; conducting monthly meetings; awarding prizes and medals; and by liaising with other learned societies within Australia and internationally. Membership is open to any person whose application is acceptable to the Society. Subscriptions for the Journal are also accepted. The Society welcomes, from members and non-members, manuscripts of research and review articles in all branches of science, art, literature and philosophy for publication in the *Journal and Proceedings*.

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Editorial

Robert E. Marks

We live in exciting times. No sooner had this year's Nobel prize for physics been awarded to the team leaders of the LIGO gravity-wave observatories that had earlier in the year reported the first detections of gravity waves — of two black holes fusing (what do they do? holes colliding?) — than Virgo, a third observatory, helped to triangulate the source of a new gravity-wave burst: two neutron stars colliding (definitely colliding) to form a black hole. Whereas not much if any radiation escapes a black-hole encounter, neutron stars colliding produce light, radio waves, X-rays, and gamma rays, which can be independently observed. But not yet neutrinos. This was accomplished with optical observatories and others corroborating the event.

A hundred years after Einstein's prediction of these ripples in space-time, mankind has developed a completely new way to observe activity in the cosmos. Moreover, the observations from the neutron-star encounter appear to confirm predictions that elements heavier than iron — gold, platinum, uranium and many of the rare-earth elements — are created during neutron star collisions.

This issue contains an absorbing report from Brynn Hibbert, the President, on the revision of the International System of Units (SI) to send the "Big K," the reference kilogram mass in Paris, to oblivion, or at least to a museum, by defining the metre, kilogram, second, and ampere (etc.) using the so-called fundamental physical constants.

There are five submitted papers. and three invited or contributed papers. The lead author of the first of the submitted papers, on the impacts of the new environmental flows on the Snowy River, is Wayne Erskine. The paper had been reviewed and revised and accepted, when I learnt of Professor Erskine's sudden death. His co-authors have written an obituary of him, which appears at the end of the paper.

The second submitted paper is a study from across the Pacific, into the use of distance sensing on Easter Island (Rapa Nui), that sad example of a land now completely denuded of the extinct Rapa Nui Palm (*Jubaea sp*.) and all other endemic trees. (Hunt and Lipo, 2006).

The third and fourth submitted papers are of historical interest, introducing a long-lost report by the geologist (and 1888 Clarke Medalist of the Royal Society), Fr. Julian Tenison-Woods (1832-1889), one of several nineteenth-century clergyman-scientists active in the Society. As Roderick O'Brien describes it, he came across the report as the appendix to an 1885 report published in the Straits Settlements (Singapore). It is here reproduced, and joins 15 earlier papers by Tenison-Woods in the *Journal*, from 1877 to 1888.

Ann Moyal, a more recent Royal Society prize-winner, has taken some 70-year-old correspondence between her late husband, the mathematician José Moyal (1910-1998), and the Nobel Laureate Cambridge physicist, P. A. M. Dirac (1902-1984), which shows Dirac struggling with the radical approach to quantum mechanics of the young, unpublished mathematician/statistician, who had recently escaped to Britain from Paris. Dirac, in effect, delayed publication of Moyal's first paper, later rewritten as two papers, and published with some support from Dirac, who was not convinced by Moyal's statistical approach to formalising quantum mechanics. In recent emails, Cosmas Zachos of the Argonne National Laboratory, commented that Dirac "believed that Poisson Brackets would solve everything, and missed the breathtaking innovation of Moyal brackets." Curtright and Zachos (2012) provide a more formal summary of the development of the phase-space interpretation of quantum mechanics, including Moyal's contribution. Meanwhile, Dirac was not alone in his skepticism: Google Scholar shows that Moyal's 1949 paper, "Quantum mechanics as a statistical theory," now has 3210 citations, and rising, and very recently I received an email confirming that Moyal's phase space approach had anticipated Richard Feynman's propagator approach by a decade or more.[1]

Reading Ann Moyal's paper, I thought I should try to obtain the original paper of J. Moyal's and publish it; Cosmas Zachos would love to see it. But, apparently, Moyal did not bring a copy to Australia with him in 1954; at any rate it is not amongst his surviving papers. What, I thought, about Dirac's collected papers, at Florida State University? Inquires turned up nothing. Then I read the complete letters, in Ann Moyal's 2006 book. Dirac always promised to return the draft after reading it. Then it hit me: with computers, photocopiers, printers, we are overwhelmed by copies of papers. But 70 years ago, if one had not made carbon copies of a draft when it was first typed up, there were only two ways of making further copies, short of retyping from scratch: photography, or off-prints after publication in a journal.[2] (There are of course many stories of the single copy of a MS lost in a taxi, flood, or fire.) So soon we forget. So, unfortunately, no copy exists of Moyal's first paper, the one he disagreed with Dirac over.

The sixth submitted paper, by Robert Young, is a reevaluation of the scientific legacy of the Rev. W. B. Clarke, founder of the Royal Society, whose contributions in several fields have been forgotten. It is appropriate to publish this reappraisal now, 150 years after the founding of the Society.

I admit to being excited by the invited papers. With the 2017 Four Academy Forum exploring, inter alia, the undermining of scientific expertise in these times of Trump, I thought it might be timely to see what science (in this case, applied psychology) could tell us about those who deny the conclusions of climate science: the deniers. Last year I had come across *The Debunking Handbook* (Cook and Lewandowsky, 2011). I approached John Cook (now at George Mason University in Virginia) to write a review article for us, which appears below. An advance copy was sent to all presenters at the 2017 Forum.

In May 2017, a new guidebook to Australian birds (Menkhorst et al. 2017) was published; as a confirmed birder I bought a copy and was struck by a chapter on the evolution and relationships among Australian birds as revealed by recent DNA analysis. The chapter was rather lost in the guidebook, I thought, and wrote to Leo Joseph, its author, to seek permission to republish it

[1] Email from Basil Hiley, Professor Emeritus of Physics at London University, of 15 November 2017.

[2] My 1969 Master's thesis, "Optimisation and plastic analysis," was typed on one of the first IBM Selectric typewriters in Melbourne, with carbon copies of the text, but I had to photograph the print-outs of the computer simulations to include them in the bound thesis.

here, which was granted. An updated version appears below.[3]

The final invited paper is a commissioned study of the Royal Society at two dates, in 1867 and 2017, as a celebration of its sesquicentenary. It is also the second paper in this issue by the indefatigable Ann Moyal.

The issue includes 11 abstracts of recent Ph.D. dissertations, from the University of New South Wales, the University of New England, Charles Sturt University, Southern Cross University, the Australian Catholic University, and the University of Canberra. (The other universities in NSW and the A.C.T. were asked to nominate outstanding theses, but have not yet responded.)

The Society, under the two recent presidents and councils, has been moving to broaden its appeal, in particular to extend beyond the physical sciences to the social sciences, the arts and humanities. Of some interest, then, might be a new magazine, *America*, the tagline of which is (in French)[4] "America like you've never read it." It was conceived to help French readers understand the U.S.A. in the age of Trump. The motivation, according to its editor, François Busnel, is that, while political experts had dismissed the possibility of Trump's success, some American novelists and writers had foreseen it. Its editorial mix includes long interviews with novelists, as well as essays and excerpts in translation. Although Australia is not as forlorn as the U.S. post September 11th, our Federal politics has been topsy-turvy for almost the last ten years. Meanwhile, the recently appointed Distinguished Fellow and Booker-Prize-winning novelist, Thomas Keneally, will give the Distinguished Fellow's Address next May, which will appear in the June 2018 issue of the *Journal*. So the Royal Society, too, is looking to novelists and writers and the humanities for insights, insights sometimes beyond the ken of scientists, of all stripes.

I thank Ed Hibbert, Rory McGuire, and Jason Antony for their assistance in the production of this issue. Remember, the *Journal* archive can be found on-line, at https://royalsoc.org.au/links-to-papers-since-1856.

Dargan, NSW,
24 November 2017

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[3] This paper is timely: recent work has confirmed that songbirds originated in Australia in the Oligocene, between 34 and 22 million years ago, and then spread to the rest of the world via Wallacea (Moyle et al., 2016).

[4] Incidentally, there has been only one paper in French in the *Journal*, by Julien Bernier, in Volume 32, 1898. And two papers (in English) by Louis Pasteur's nephew, Adrien Loir, in Volume 25, 1891.

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Standards and units: a view from the President of the Royal Society of New South Wales

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Abstract

As the Royal Society of New South Wales continues to grow in numbers and influence, the retiring president reflects on the achievements of the Society in the 21st century and describes the impending changes in the International System of Units. Scientific debates that have far reaching social effects should be the province of an Enlightenment society such as the RSNSW.

Introduction

It may be a long bow, but the changes in the definitions of units used across the world that have been decades in the making, might have resonances in the resurgence in the fortunes of the RSNSW in the 21st century. First, we have a system of units tracing back to the nineteenth century that starts with little traction in the world but eventually becomes the bedrock of science, trade, health, indeed any measurement-based activity. Second, the RSNSW, similarly aged and arising out of the great Enlightenment push for understanding and knowledge, might not have underpinned quite such a wide movement, but is now finding its niche as a place for thoughtful people to meet, receive knowledge, and reflect on the modern and complex world we live in. Although science heavy, it is interesting that the Forums, where we come together with the four learned Academies in Australia have been on the bigger questions of "The Future of Work", "Society as a Complex System" and "The Future of Rationality in a Post Truth World". Each of these 'hard' problems is informed by science, but not solved by science alone. Our own Society embraces "science literature philosophy and art" and we see with increasing clarity that our business often spans all these fields. As we shall learn the choice of units with which to measure our world is driven by science, philosophy, history and a large measure of social acceptability, not to mention the occasional forearm of a Pharaoh.

Measurement

We take measurement for granted. Each of us has an idea of our height, weight, age, how far it is from Sydney to Brisbane, the freezing point of water, and so on. There is little need to reflect on how these concepts come about and how numbers can be put upon specific instances. We might remember there can be different systems of units; water freezes at the same temperature, but we can call that temperature 0 °C, 32 °F or 273.15 K.

Do we worry about measurement uncertainty? Our three freezing point temperatures imply very different levels of precision, as suggested by the number of digits used to give the numerical value. We might say that Sydney to Brisbane is 1 thousand kilometres, and be sufficiently correct to the nearest thousand (the crow-flies distance is 733 km, Google maps offers 922.3 km to drive). A high quality, single-frequency global positioning system (GPS) has an horizontal accuracy of less than 1.9 m for 95% of measurements (William J. Hughes Technical Center WAAS T&E Team, 2017), so if we wanted to we could measure the distance between points in Sydney and Melbourne to be, say, 733875.5 m with an uncertainty of ± 2.7 m (√2 x 1.9 m). Such are the achievements of the 21st century.

Metrology

Metrology (no, not meteorology), is the science of measurement and has an international infrastructure that maintains our understanding of this important human activity. Eight international organisations[1] come together in the Joint Committee for Guides in Metrology and through its two working groups prepares the *Guide to the Expression of Uncertainty in Measurement* (GUM) (Joint Committee for Guides in Metrology, 2008) and the *International Vocabulary of Metrology* (VIM) (Joint Committee for Guides in Metrology, 2012).

Figure 1: Pavillon de Breteuil, home of Bureau Internationale des Poids et Mesures (BIPM) (photo: D B Hibbert, 2012)

These bodies meet at the BIPM on the outskirts of Paris (Fig. 1), and for many years the author travelled twice a year to sit on the GUM working group representing IUPAC. It is a hard life, but someone has to do it.

This essay concerns the measurement of quantities the values of which are represented by a "number and a reference together expressing magnitude" [VIM 1.19][2]. The 'reference' is our unit without which the number has no meaning. (Consider if you were told water freezes at 0, 32 or 273.15). So far so good, but where do units come from?

A Brief History of Units

As soon as you want to pass on information about the magnitude of something the concept of an agreed example of that quantity to serve as a unit becomes evident.

[1] International Bureau of Weights and Measures (BIPM), International Electrotechnical Commission (IEC), International Federation of Clinical Chemistry and Laboratory Medicine (IFCC), International Organization for Standardization (ISO), International Union of Pure and Applied Chemistry (IUPAC), International Union of Pure and Applied Physics (IUPAP), International Organization of Legal Metrology (OIML), International Laboratory Accreditation Cooperation (ILAC).

[2] Where terms are defined in the International Vocabulary of Metrology (VIM) the entry number is given in square brackets [VIM x.y]. See Joint Committee for Guides in Metrology, 2012.

Figure 2: Papyrus showing weighing the souls of the dead and a copy of the Royal Cubit. (courtesy Paul De Bièvre)

Counting (enumeration) of objects predates measurement as such, where the unit is 'one thing', but very quickly after the introduction of writing we see references to standards of length, volume and weight appearing in the Middle East, particularly Ancient Egypt and Mesopotamia, and in China. For example the Royal Cubit (Fig. 2), the length of the Pharaoh's forearm and hand was used as a length standard in constructing the Pyramids and for monitoring the depth of flooding of the Nile in the period between 3000 and 2700 BCE (Clagett, 1999).

Very quickly the utility of standards spread and we find examples in every society (Fig. 3).

Figure 3: Chinese weight from the Warring States Period 244 BCE (Photo D B Hibbert)

Mediæval Europe and the need for standardisation of the standards

Kings were particularly keen on standards, no doubt something to do with taxes. Having standardised measures is prescribed in Magna Carta, and then at different times after that standards were issued by the crown. Edward I of England required each town to have an 'ellwand', a rod the length of an ell (about 46 cm or twice that depending on who you read). The ell was a realisation of the old cubit being about the distance from an elbow to the tip of the middle finger. Not surprisingly there were many versions of the ell named after the country or town of origin, and none were the same. The plethora of standards between and within countries would have been seen as an impediment to trade. Discussions of what would become the 'metric system' start with Bishop John Wilkins FRS (1614–1672), the first secretary of the Royal Society of London. He was asked by the Society to devise a universal standard of measure. In 1668, in Chapter VII in his book *An Essay towards a Real Character and a Philosophical Language*, which mostly dealt with the possibility of an international language, he proposed a system of measurement based on a decimal system (Wilkins, 1668). It was the French however who then made all the running.

Metric systems and the SI

The creation of the decimal metric system and the subsequent deposition of two platinum standards representing the metre and the kilogram, on 22 June 1799, in the Archives de la République in Paris can be seen as the first step in the development of the present International System of Units. Carl Friedrich Gauss (1777–1855) promoted the application of this decimal metric system, together with the second which was defined in astronomy, as a coherent system of units [VIM 1.14] for the physical sciences. The Metre Convention (Convention du Mètre), signed by delegates from seventeen countries on 20 May 1875, established, by Article 1, the Bureau International des Poids et Mesures, the BIPM (BIPM, 2007), charged with providing the basis for a single, coherent system of measurements to be used throughout the world. The General Conference of Weights and Measures (CGPM) was also established, and work began on the construction of new international prototypes of the metre and kilogram. Together with the astronomical second as the unit of time, these units constituted a three-dimensional mechanical unit system with the base units metre, kilogram, and second, the MKS system. The system developed and, in 1960, at the 11th CGPM it was called the International System of Units (Système International d'Unités), SI [VIM 1.16]. The SI has now seven base units [VIM 1.10] from which other units can be derived (for example the unit of energy, joule J which is kg m^2 s^{-2}). See Table 1 and (BIPM, 2014). It is the proposed revision of the SI to which I shall devote the rest of this address.

Table 1: Base units of the SI

Base quantity	Name of unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Definitions of units

The base units of the SI have been defined after much discussion of how best to obtain the following: "units should be chosen so that they are readily available to all, are constant throughout time and space, and are easy to realize with high accuracy" (BIPM, 2014). Falling foul of "readily available to all" the kilogram is defined as the mass of the international prototype of the kilogram, an object made of platinum and iridium, which is held in two safes under three bell jars in the basement of the BIPM. It has only been brought out on three occasions since its manufacture in the 1890s. Metrological traceability [VIM 2.41] of mass measurements to this artefact is achieved through six copies held at the BIPM, tens more distributed to the National Measurement Institutes of many countries, and then thousands of standard weights that are used to calibrate balances, even unto weighing potatoes at your local supermarket. The 'Big K', as it is affectionately known, is the only material object in the SI. The metre, the unit of length, once being defined by a standard platinum-iridium bar that was constructed to be a particular fraction of the distance between two points on the Earth, is now the distance light travels in a vacuum in 1/299 792 458 of a second. Even though you or I might find it difficult to create a metre so defined, this definition of metre no longer makes a single thing at a particular place on Earth the sole ultimate realisation of the unit. This definition also leads to the question of where we get the rather short time from, the answer being by knowing the speed of light with exceptional accuracy. In fact, if you consider it, if metre is defined as written above then the speed of light in a vacuum has to be exactly 299 792 458 m s^{-1}. More of fixing values of phenomena later.

Mise en practique

Reflecting on the discussion of how to define units you might have realised that the definition is one thing, but how is it to be used to actually measure a quantity in the real world is something else. The set of instructions on how to 'make' a unit at the highest metrological level is called the *mise en practique*. Although the kilogram is reviled for being an artefact, its *mise en practique* is quite clear, essentially being "take the Big K out of its bell jars and safes, buff it up with a chamois leather cloth and some propanol, and weigh one of its six copies against it." The potatoes in the supermarket gain the benefit of this practice by a long chain of subsequent comparisons of weights establishing the so-called metrological traceability chain [VIM 2.42] (De Bièvre et al., 2011). As for the rest their *mise en practique* can be quite tricky.

How to make a new SI

Replacing the kilogram

It is not just the dear old kilo that is on the nose. We also realised that the definition of the ampere, the unit of electric current, was not exactly easy to realise. (The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per metre of length.) Rather than the super-scientific application of the Enlightenment, it turns out that the SI is a bunch of nearly *ad hoc* definitions that work together, but only just. There are many reasons, not just scientific ones, that have led to the present SI, supporting my contention that what we do, even in the name of high science, is ultimately a human activity relying as well on "literature philosophy and art."

The "New SI"

Thank you for bearing with me. And now with a drum roll I give you news of the completely new SI. More than a decade in the planning (CPGM, 2007) and most recently resolved by the CGPM in 2014 (CPGM, 2014), the new approach has turned on their heads the concept of definition of a unit and measurement of fundamental constants. At present having set up a system of units we go into the world and measure quantities (mass of potatoes etc.). A set of quantities of great importance to science are so-called fundamental physical constants of Nature (NIST, 2014). We have already encountered the speed of light in a vacuum. Another is the Boltzmann constant, and another is the atomic fine splitting constant. Knowing, by measurement, these constants to the best accuracy we can manage is important to just about every activity in science. We can measure the values of these constants, with measurement uncertainty, because we have defined units in the SI. The point about fundamental physical constants is that we believe they are constant anywhere in the universe and for all time (since a bit after the Big Bang). We write

$$\text{quantity} = \text{number} \times \text{unit}, \qquad (1)$$

(e.g. the Planck constant, h = 6.626 070 040(81).10^{-34} × joule second, where (81) at the end gives the standard measurement uncertainty [VIM 2.30] in the last two figures). The value has uncertainty because the quantity is measured. Now suppose we decide that the measured value is the very best we can obtain and so can be fixed without uncertainty. We assert that the actual quantity in Nature is fixed in value, and now we have a fixed number. Et voila! According to Eq. (1), if two out of the three terms are fixed, the third – the unit – is now defined without uncertainty. A definition of the unit joule second (symbol J s) would therefore be "The unit of action, J s, is that action for which the Planck constant has a value of exactly $6.626\ 070\ 040.10^{-34}$ × joule second." To avoid changing the base quantities for which we determine base units (Table 1) it has been decided to fix enough constants that the existing base units can still be defined. As will be decreed by the CPGM at its 26th meeting in 2018 (Richard and Ullrich, 2017), the (new) SI will be the system of units in which:

- the ground state hyperfine splitting frequency of the caesium 133 atom $\Delta\nu\ (^{133}\mathrm{Cs})_{\mathrm{hfs}}$ is exactly 9 192 631 770 × hertz,
- the speed of light in vacuum c is exactly 299 792 458 × metre per second,
- the Planck constant h is exactly $6.626\ 070\ 15.10^{-34}$ × joule second,
- the elementary charge e is exactly $1.602\ 176\ 634.10^{-19}$ × coulomb,
- the Boltzmann constant k_{B} is exactly $1.380\ 649.10^{-23}$ × joule per kelvin,
- the Avogadro constant N_{A} is exactly $6.022\ 140\ 76.10^{23}$ × reciprocal mole,
- the luminous efficacy K_{cd} of monochromatic radiation of frequency 540.10^{12} × Hz is exactly 683 lumen per watt,

where

> the hertz, joule, coulomb, lumen, and watt, with unit symbols Hz, J, C, lm, and W, respectively, are related to the units second, metre, kilogram, ampere, kelvin, mole, and candela, with unit symbols s, m, kg, A, K, mol, and cd, respectively, according to Hz = s^{-1}, J = $\mathrm{m}^2\ \mathrm{kg\ s}^{-2}$, C = s A, lm = cd $\mathrm{m}^2\ \mathrm{m}^{-2}$ = cd sr, and W = $\mathrm{m}^2\ \mathrm{kg\ s}^{-3}$.

Arguments for and against the New SI

Opinion was that the old SI had gone as far as it could, and perhaps something needed doing, at least for the ampere and kilogram. The chemists had never been comfortable with the quantity 'amount of substance' measured in mole or indeed the Avogadro constant with units mol^{-1}. We (I am an analytical chemist) have more or less ignored the SI as far as measuring the numerosity of atoms and molecules. Older concepts of 'gram mole' and an Avogadro number as a kind of chemist's dozen are still widely taught even by university lecturers, who in theory should know better.

Despite wide acceptance of the need for change and somewhat reluctant support for the proposed New SI, there is still a loud complaint from the periphery, outside the BIPM and National Measurement Institutes and the major international organizations. (Hill, 2011). Apart from moaning about lack of transparency of the process (many discussions are behind closed doors, but science was never a democracy), the main arguments against are:

- There are no more independent base units. The seven defining constants are taken together to make all units, base or otherwise. See Fig. 4. However, this interdependency means that errors in any one assignment will impact the rest, with the exception of the mole which only depends on the Avogadro constant.

- Are the constants of Nature truly constant? If one is not, even ones not immediately in the chosen seven, for example the fine structure constant, because we have fixed the numerical value, and we no longer measure the constant, we can only infer changes through other measurements.

- Are these definitions teachable and understandable by all but the most sophisticated scientists? (Barański, 2013)
- Chemists have supported the unit of mass being related to the dalton (Da), which is presently defined as 1/12 the mass of an unbound ^{12}C atom with measured value 1.660 538 782(83) kg, rather than the Planck constant with its quantum mechanical associations. The gram to dalton ratio is the Avogadro number, but this definitional agreement will no longer hold in the proposed new SI, although practically nothing will change.

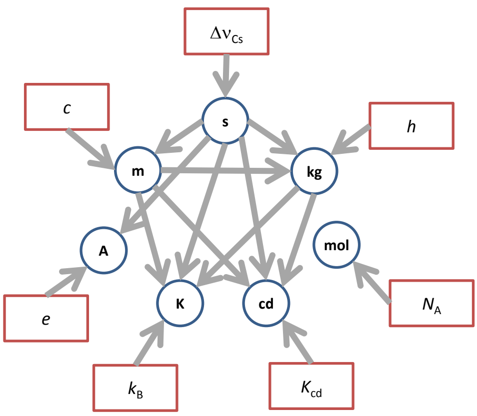

Figure 4: Relationships and dependencies among the seven base units of the SI (circles) and the defining fundamental physical constants (rectangles). See text for description of symbols.

These concerns are mostly answered:

- There is really no need to have base units anymore, although the new SI will be cast in terms of the old base units for continuity. The SI is a coherent system, and the correlation among units actually leads to smaller uncertainties of measurement.
- While there has long been discussion about the constancy of fundamental constants (Dirac, 1938) on the scale of the Universe, it is not likely that the values of the chosen constants will change appreciably any time soon.
- Some of the definitions might not be as straightforward as they used to be, but practically nothing will change. Australia will still have its national standard kilogram against which all weights in the country will be measured.
- The use of the Planck constant over the dalton is admittedly not the preferred option for chemistry but it works better for the SI as a whole with the set of constants chosen. Defining two out of kilogram, Avogadro constant and dalton is a matter of choice – sorry we didn't choose yours.

Realising the kilogram and Avogadro constant

An excellent result from the whole process is that a great effort has been put into realising the kilogram via the Kibble Balance (before called the watt balance) – see Chao et al., (2015) for a LEGO® version that can be constructed at home – and the Avogadro constant by the 'silicon route'. Chemists and metrologists, and particularly Australian chemists and metrologists, have undertaken a worldwide experiment in which the purest silicon 28 is made into the most perfect spheres. By X-ray diffraction the dimensions of the silicon unit cell are measured and then the volume of a weighed silicon 28 sphere (Fig. 5) is measured. The ratio of the molar volume to the atomic volume is the

Avogadro constant (Hibbert, 2008). Fig. 5 shows Australia's contribution to the project, which was to fashion the silicon spheres by, in the last stages, hand polishing with jewellers' rouge. Measurements of the sphere's diameter reveal an almost perfect surface.

Figure 5: Walter Giardini of the National Measurement Institute Australia holding a silicon sphere as part of the Avogadro project. (photo D B Hibbert)

Discussion and Conclusions

As I compiled this brief account of units, I see personal, national and international rivalry, and scientific arguments being made in wonderfully self-serving ways. The French were the problem in the old days. Before signing of the Treaty of the Metre in 1875 France had the prototypes of the metre and the kilogram, but the military successes of Germany and the commercial hegemony of Britain meant that offering them to the international community was the only way to keep the standards in Paris, albeit in the new international organisation BIPM. The USA was an original signatory to the Treaty, but has cleaved to its version of British Imperial units ever since. Britain, although attending the metre convention in 1875, wouldn't have a bar of the new Treaty, even though they had pioneered the idea, and a British company, Johnson Matthey, made the prototypes and copies of the kilogram and metre. Britain did join in 1884, and Australia became a formal member in its own right in 1947.

The anarchy of the debate around the most recent changes in the SI has detracted from the great effort the world is putting into global standards. Early attempts to steamroller the changes caused a backlash that has taken years to sort out. I happened to vote for the changes presented without warning at an IUPAC (International Union of Pure and Applied Chemistry) meeting in Glasgow in 2009, the support endorsed by the IUPAC Council. Realising I had not made a considered decision my division mounted opposition for the next four years until IUPAC created a union-wide project to consider the changes to the SI. This reported in 2017 (Marquardt et al., 2017), after extensive consultation in the chemical community, recommending again acceptance of the proposed changes but with a new suggestion for the definition of the mole.

Perhaps only a society that boasts the breadth of interest as the RSNSW is equipped to advise and debate the most momentous issues of the day. If climate change had not been fought over as a purely scientific proposition, but from the start the social and political aspects had been properly integrated into the debate, we might be in a better place. The Royal Society of New South Wales has a serious future in supporting the 'whole of human activity' approach to problems, and I have valued my part in bringing this about.

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Bedform maintenance and pool destratification by the new environmental flows on the Snowy River downstream of the Jindabyne Dam, New South Wales

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Abstract

The hydrology, geomorphology and aquatic ecology of the Snowy River below the Snowy Mountains Hydroelectric Scheme were greatly altered by large-scale interbasin water transfers for power generation and the supply of water for irrigation until recent increases in environmental flow releases from Jindabyne Dam. Between 1967 and 2000 maximum releases from Jindabyne Dam were smaller than the lowest ever recorded mean daily discharge before flow regulation. The New South Wales and Victorian Governments agreed to return up to 28% of the natural mean annual flow to the river in keeping with recommendations from a community-sponsored Expert Panel. Detailed analyses of bedforms for 303 continuous km below the Scheme indicate that the new environmental flow regime will increase the pool-riffle spacing by between 3 and 294 m by increasing scour of pools and runs, and by reversing long-term channel contraction and pool infilling. Furthermore, strong thermal gradients and persistent oxygen stratification that produce bottom anoxia in upland pools will not develop under most environmental flows because of strong mixing. Even marked salt stratification in the upper estuary which can produce density differences of up to 14.9 kg/m^3 between surface and bottom waters is unlikely to develop in future.

Introduction

A key issue for many regulated rivers throughout the world is the determination of environmental flows to sustain aquatic ecosystems, to restore rivers degraded by flow regulation and to protect biodiversity for future generations (Petts 1996; Arthington et al. 2006; Poff et al. 2010; Williams, 2017). The basis of the problem is the conflict between the needs of aquatic ecosystems and the consumptive and economic requirements of water users (Petts 1996; Arthington et al. 2006; Poff et al. 2010). Dam releases driven by power generation, irrigation and water supply needs have greatly altered the timing, magnitude and duration of flows and sediment fluxes, thus severely degrading the morphology and habitat of many Australian rivers and their water-dependent flora and fauna (for example, Sherrard and Erskine 1991; Benn and Erskine 1994; Sammut and Erskine 1995; Erskine 1996a; Erskine et al. 1999a; 1999b; Arthington et al. 2006).

Large interbasin water transfers for hydroelectric power generation substantially changed the hydrology of the Snowy River downstream of Jindayne Dam between 1967 and 2000 (Figure 1). The maximum releases from the dam before recent structural changes to the outlet and spillway were usually only 63% of the lowest mean daily discharge ever recorded at the same site over the 54 years before the Scheme (Brizga & Finlayson 1994; Erskine et al. 1999a). Such hydrologic changes have also significantly impacted on the geomorphology and aquatic ecology of the river (Davies et al. 1992; Brizga & Finlayson 1994; Erskine et al. 1999a; 1999b; 2001; Turner & Erskine 2005). According to Brookes and Shields (1996), river rehabilitation refers to a partial return of a river to a pre-regulation structure or function which can require enormous amounts of expenditure (Williams 2017).

The implementation of a 'restoration protocol' (Stanford et al. 1996; Lake et al. 2007) or an 'ecologically acceptable flow regime' (Petts 1996; Poff et al. 1997) which will partially reverse the recent geo-ecological changes of the Snowy River was first proposed by a community-sponsored expert panel (Anon 1996).

The Snowy Water Inquiry was set up as part of the corporatization of the Scheme's management authority. The Inquiry provided, among other things, the New South Wales and Victorian Governments with fully costed options for the restoration of the Snowy River (Anon. 1998). However, the Inquiry never considered the restoration option, i.e. the complete structural and functional return of the Snowy River to a pre-regulation state (Brookes & Shields 1996). The Inquiry's recommended flow option (option D) involved the release of 10% of the pre-Scheme mean annual flow from Jindabyne Dam with another 5% being delivered by the decommissioning of the Mowamba River Aqueduct. This option was supposedly sufficient to provide minimum habitat utilisation flows, flushing flows and channel maintenance flows. However, these flows were not quantified. The Inquiry's composite option F crudely approximated the Expert Panel's (Anon. 1996) recommended flow regime (25% of the pre-Scheme mean annual flow) but was not recommended (Anon. 1998). River and catchment works were also recommended to further improve stream condition (Anon 1998). A similar situation has also occurred more recently throughout the Murray-Darling basin (Williams 2017).

The New South Wales and Victorian Governments did not implement the Inquiry's recommendations. Instead a new water allocation was finalized on 6 October 2000 following the efforts of Victorian Independent MP Mr Craig Ingram. It was agreed that A\$300 x 10^6 would be spent over the next 10 years to return 21% of the natural mean annual flow to the Snowy River. A subsequent increase to 28% was envisaged after 10 years. Rose (2017) has shown that the new environmental flow regime has certainly improved, to some degree, river condition and health.

The purpose of this paper is to determine whether the Expert Panel's recommended environmental flows were adequate to reverse channel contraction and pool infilling by increasing bedforms and aquatic habitats, and to destratify upland pools near Jindabyne Dam as well as shallow pools in the upper estuary. Turner & Erskine (2005) established that upland pools and pools in the upper estuary were occasionally oxygen stratified during low flows and/or unusually hot weather. These issues were not considered by the Expert Panel (Anon. 1996) or by the Snowy Water Inquiry (Anon. 1998) or by previous research on the Snowy estuary (Hinwood & McLean 1999a; 1999b). The Snowy Mountains Hydroelectric Scheme (SMHS) is briefly outlined below because it is necessary to appreciate the magnitude of its impacts on the Snowy River below Jindabyne Dam.

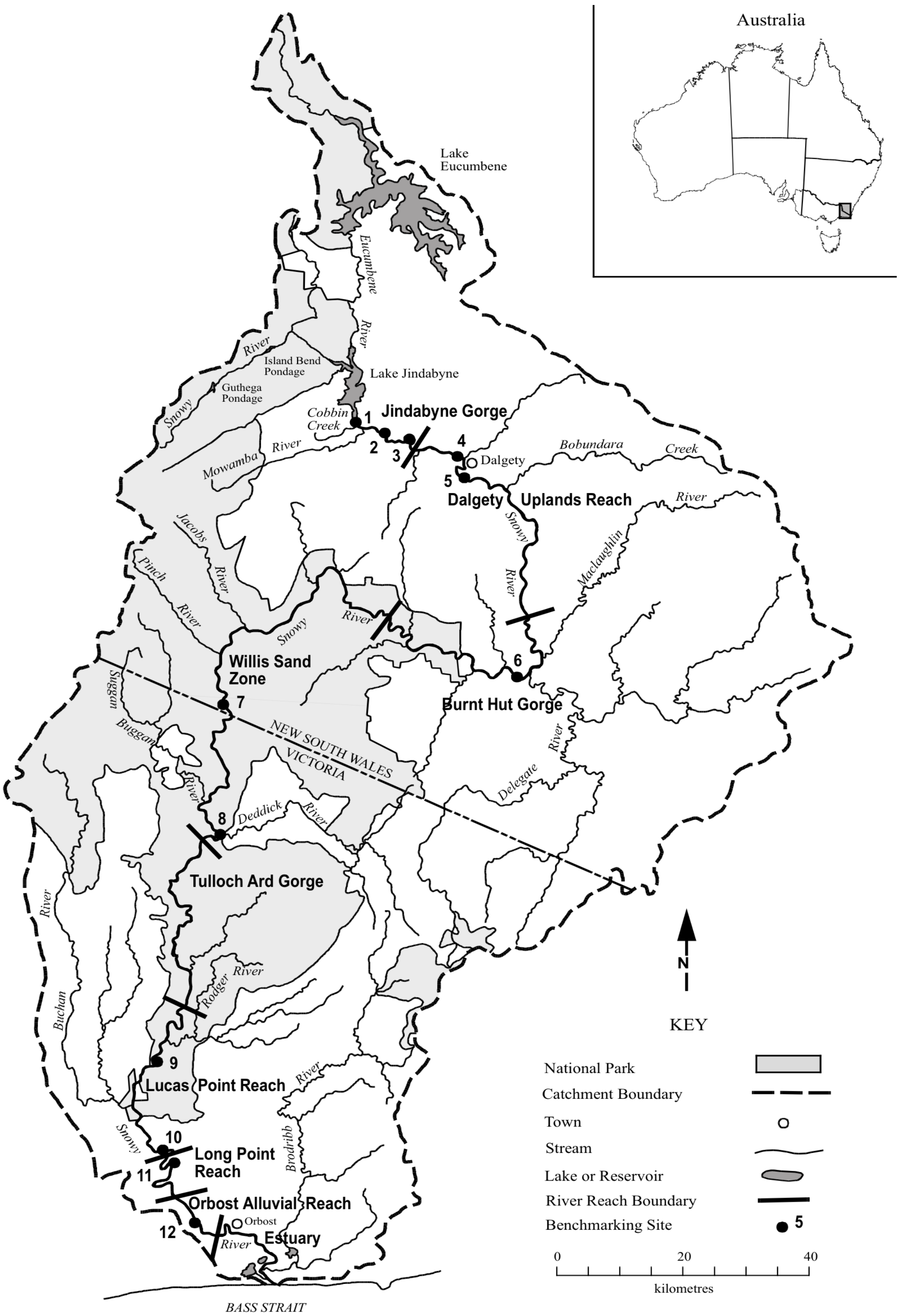
Snowy Mountains Hydroelectric Scheme

The SMHS diverts water from the upper Snowy, Murrumbidgee and Tooma rivers in the Snowy Mountains into either the Tumut or Swampy Plains River, generating hydroelectric power in the process. The Scheme was built between 1949 and 1974 at an historical cost of A$800 x 10^6 (Frost 1983). Engineering features of the Scheme include 16 large dams, many more smaller structures, 145 km of tunnels, seven power stations, one pumping station and 80 km of aqueducts (Anon 1993; Dann 1969; 1970). The total generating capacity of the Scheme is 3.74 x 10^6 kW and, on average, 2.36 x 10^9 m^3/yr of additional water is made available for irrigation purposes on the Murray and Murrumbidgee rivers (Anon 1993).

Just within the Snowy River catchment, there are two large dams (Eucumbene and Jindabyne), two small dams (Guthega and Island Bend), one pumping station, one power station, five tunnels and nine aqueducts (Anon. 1993). Eucumbene and Jindabyne Dams are the most important in terms of their effect on flow regulation of the Snowy River and Eucumbene Dam is the largest reservoir in the SMHS (Anon. 1993).

Jindabyne Dam stores runoff from the Snowy River catchment below Island Bend and Eucumbene Dams as well as spills and releases from both dams (Figure 1). Eucumbene Dam has never spilled. The original siphon outlet on Jindabyne Dam could release up to 0.57 m^3/s (Howard & Holliday 1968) and was rebuilt to release the new environmental flows (see below). The Mowamba River Aqueduct diverts up to 4.8 m^3/s from Cobbin Creek and Mowamba River, two right bank tributaries of the Snowy below Jindabyne, upstream into Jindabyne Dam (Howard & Holliday 1968). In 1961, the licensing authority determined the releases from Jindabyne Dam only on the basis of the existing and predicted downstream consumptive water uses to be ‘visible flow’ in the Snowy River above its junction with the Mowamba River, a discharge of not less than 0.081 m^3/s immediately downstream of the Mowamba River, a discharge of not less than 0.284 m^3/s immediately downstream of the Dalgety gauging station, a discharge of not less than 0.197 m^3/s immediately downstream of the Snowy-Delegate rivers junction and a maximum release from Jindabyne Dam of 0.57 m^3/s or the estimated natural inflow to the reservoir when less than 0.57 m^3/s (Clarke & Bate 1992; Bate & Whalley 1993).

Figure 1 (opposite): The Snowy River catchment showing the river reaches defined in Table 1 and Snowy River benchmarking sites, some of which were used for stratification studies.


Australia
Lake Eucumbene
Eucumbene River
Lake Jindabyne
Island Bend Pondage
Guthega Pondage
Snowy River
Cobbin Creek
Jindabyne Gorge
Dalgety
Bobundara Creek
Mowamba River
Dalgety Uplands Reach
Maclaughlin River
Snowy River
Jacobs River
Pinch River
Willis Sand Zone
Burnt Hut Gorge
Delegate River
NEW SOUTH WALES
VICTORIA
Suggan Buggan River
Deddick River
Tulloch Ard Gorge
Rodger River
Buchan River
Lucas Point Reach
Long Point Reach
Brodribb River
Orbost Alluvial Reach
Orbost
Estuary
BASS STRAIT
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KEY
National Park
Catchment Boundary
Town
Stream
Lake or Reservoir
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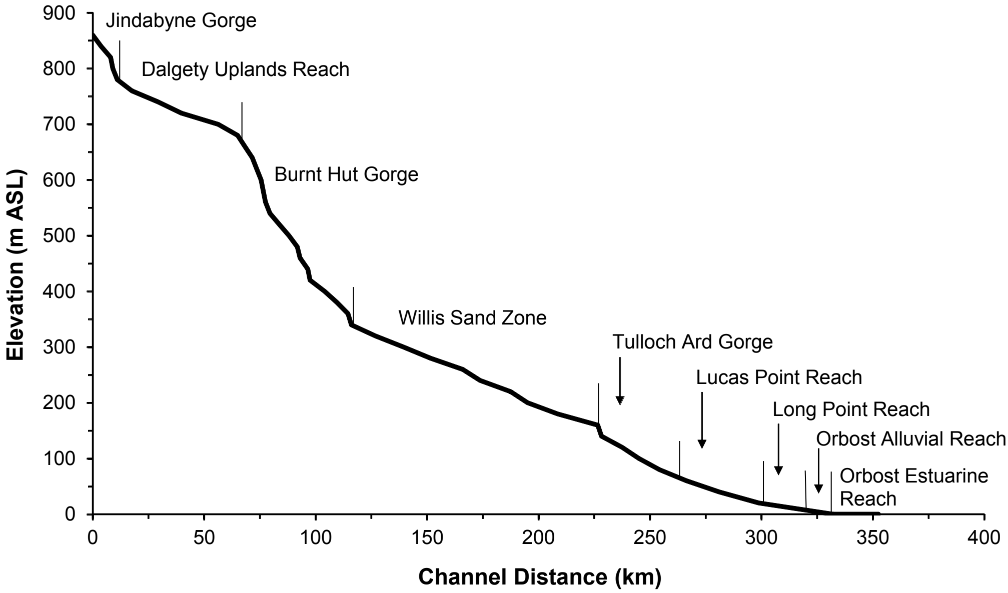

Figure 2: Longitudinal profile of the 352.5 km of the Snowy River downstream of Jindabyne Dam compiled from 1:25,000 and 1:50,000 topographic maps. The channel reaches outlined in Table 1 and mapped in Figure 1 are also shown.

Table 1: Channel reaches in italics and post-regulation changes in flows, sediment inputs, channel morphology, bed sediment and riparian vegetation on the Snowy River below Jindabyne Dam. Bedform terminology follows Grant et al. (1990). Channel reaches are shown in Figures 1 and 2. River types follow Erskine et al. 2017.

Channel Reach	**Reach Characteristics**	**Post-Regulation Channel Changes up to 2000**
Jindabyne Gorge (11.5 km long) Granodiorite Gorge river type	Channel deeply incised into plateau of Late Silurian granodiorite of the Kosciuszko Batholith, producing a gorge. River debouches from the gorge at the Barneys Range fault scarp. Bedrock and boulders laterally and vertically confine the channel, producing a steep slope (7.1 m/km) punctuated by gravel riffles, rapids and cascades with boulder and bedrock steps separating occasional long remnant pools, especially on valley bends. There is often a narrow inner bedrock channel flanked by bedrock shelves veneered with thin sediment deposits and peat. Limited bar and bench development at valley expansions and bends, and downstream of tributary junctions.	Mean annual flow reduced by 98% and all floods suppressed. Episodic thermal and oxygen stratification develops in deep remnant pools. Channel contraction; vegetation invasion on channel margins; pool infilling with clastic and biogenic sediment; formation of *Phragmites australis* chokes on former riffles, tributary mouth bars and thick fine-grained sediment laminae in bed; peat formation on bedrock ledges beside inner bedrock channel. Fine sediment intrusion into bed sediment; lichen colonization of exposed bedrock surfaces.
Dalgety Uplands Reach (57.5 km long) Laterally bedrock confined and vertically bedrock constrained river type	Channel flows across Monaro Tableland and frequently impinges against or flows across a range of rocks of Ordovician Adaminaby Group and Late Silurian granodiorite and adamellite of the Berridale Batholith. Short sections of gorge occur repetitively. Flatter bed slope (2.1 m/km). Well-developed, vegetated bars of sand and gravel. Relatively shallow pools floored by fine-grained sediment laminae and submerged macrophytes. Limited floodplain development.	Mean annual flow reduced by 94% and flood flows greatly suppressed. Channel contraction; vegetation invasion of channel margins; bed aggradation and sediment storage; formation of *Phragmites australis* chokes, tributary mouth bars and thick fine-grained sediment laminae in bed; fine sediment intrusion into bed. Lichen colonization of exposed bedrock surfaces.
Burnt Hut Gorge (57 km long) Adamellite Gorge river type	Steep gorge (5.9 m/km) cut into Monaro Tableland, exposing mostly Late Silurian adamellite of the Berridale Batholith and Silurian Yalmy Group. Bedrock fall (Snowy Falls) at downstream end. River closely vertically constrained and laterally confined by bedrock. Channel characterised by steep bedrock and gravel rapids and long pools.	Substantial flow reduction. Suspended sediment plumes generated by unregulated Delegate River. Sand inputs from gully erosion of granitoid areas on Monaro Tableland. Vegetation invasion, particularly by exotic tree species; fine sediment intrusion into bed.

Channel Reach	Reach Characteristics	Post-Regulation Channel Changes up to 2000
Willis Sand Zone (93.5 km long) Laterally bedrock confined and vertically bedrock constrained river type	Channel alternates between relatively flat, sand-bed sections flanked by extensive side bars and steeper bedrock sections with rapids, falls and bedrock inner channels. Slope much less than upstream (1.6 m/km). Valley floor trough wider than upstream. Granodiorite and adamellite of the Kosciuszko Batholith outcrop in bed.	Substantial flow reduction. Substantial historical local sand input from soil erosion. Vegetation invasion, particularly by exotic plant species; loss of native riparian trees due to lower water tables; extensive sandy side bar and bench development in flatter sections.
Tulloch Ard Gorge (41.5 km long) Volcanic Gorge river type	Deep, narrow channel cut through resistant granodiorite and Snowy River Volcanics Group. Steep bedrock gorge (2.4 m/km) with long pools and steep rapids, cascades and falls.	Substantial flow reduction. Little sediment storage in channel, except in large pools; and weed invasion of riparian zone.
Lucas Point Reach (22.5 km long) Laterally bedrock confined and vertically bedrock constrained river type	Channel laterally confined and vertically constrained by bedrock. Slope less than upstream (1.2 m/km) deep pools present and some sand storage in pools, point bars and benches. Bedrock and gravel rapids, gravel armoured bars and small inner bedrock channel present.	Mean annual flow reduced by 29%. Vegetation invasion, particularly by exotic plant species in the riparian zone; sand storage in pools, bars and benches.
Long Point Reach (18 km long) Laterally bedrock confined river type	Deeply incised, irregular, sinuous bedrock valley which laterally confines channel. Abrupt change to sandy bed-material because of slope reduction (0.7 m/km). Common sand bars and benches with spatially disjunct riparian vegetation.	Mean annual flow reduced by 12%. Exotic vegetation invasion; pools rapidly infilled with sand after flood scour; substantial sand storage in the bed but gravel armoured sections still occur.
Orbost Alluvial Reach (11 km long) Straight sand-bed channel river type	Extensive floodplain borders sand-bed channel which occasionally impinges against bedrock valley sides. Relatively straight sand-bed channel in upstream section with transverse, longitudinal and side bars, often flanked by benches. Slightly sinuous channel with point bars further downstream. Smaller channel capacity in slightly sinuous section because of extensive flood channels on the floodplain.	Substantial flow reduction. Replacement of bank-attached, alternating sandy side bars with sandy transverse and longitudinal bars in straight section; loss of small pools opposite side bars in straight section; sand storage in channel. Loss of native riparian vegetation and weed invasion of riparian zone.

Channel Reach	Reach Characteristics	Post-Regulation Channel Changes up to 2000
Orbost Estuarine Reach (20.5 km long) Sand-bed estuarine channel river type	Barrier type estuary (Roy 1984) at an advanced stage of infilling with fluviatile and marine sediment. Estuarine lakes still present in side embayments. Fluvial sand slug extends to mouth of the Little Snowy River. Sand transported to coast. Extensive sections of *Phragmites australis*-lined and pasture-covered banks. Mouth episodically closes due to sedimentation. Occasional cutoffs present.	Thermal, oxygen and salt stratification develops during prolonged low summer flows in upper estuary. Bank-attached, alternating side bars largely replaced with transverse and longitudinal bars in upper estuary; sand storage in channel as a sand slug in upper estuary. Substantial erosion of estuarine islands in lower estuary.

Recommended environmental flows

The Government agreed environmental flow regime for the Snowy River downstream of Jindabyne Dam was to progressively return 28% of the natural mean annual flow over more than 10 years so that the Expert Panel's (Anon. 1996) targets were achieved. The Expert Panel's environmental flow regime is outlined because it is used below to assess bedform maintenance and pool destratification. An annual flood of up to 139 m^3/s for 3-5 days at Jindabyne and at least 231.5 m^3/s at Dalgety was recommended to create and enlarge the channel so as to reverse channel contraction, pool infilling, riparian vegetation invasion and fine sediment intrusion into the bed (Rose 2017). The range of flood peak discharges with annual exceedance probabilities of 99 to 1% before flow regulation at Jindabyne was relatively small (125.8 to 1093 m^3/s) (Erskine et al. 1999a). As a result, flood variability as measured by the Flash Flood Magnitude Index of Baker (1977) was only 0.202, which is low by Australian standards (McMahon et al. 1992; Erskine 1986; 1996b; Erskine & Saynor 1996; Erskine & Livingstone 1999). Therefore, natural channel-forming discharges before flow regulation were moderate floods of frequent occurrence equivalent to or less than the mean annual flood (411 m^3/s) (Leopold et al. 1964; Dury 1976; Baker 1977). The large bank-full capacities reported elsewhere in New South Wales by Pickup & Warner (1976), Nanson (1986) and Erskine (1994; 1996b), among others, do not apply here because of low flood variability. The smallest recorded unregulated annual flood occurred in 1938 and was only 123 m^3/s, so the Expert Panel recommended an annual flood of 139 m^3/s to initiate fluvial disturbance to reverse long-term channel shrinkage but not to re-establish the pre-Scheme channel, i.e. rehabilitation, not restoration.

Natural monthly streamflows at Jindabyne before regulation increased progressively from February to October before declining progressively to February (Erskine et al. 1999a). Similar seasonal flow distributions for unregulated conditions were recorded at the Dalgety, Basin Creek and Jarrahmond gauges (Erskine et al. 1999a). The need for variable flows on at least a monthly scale but preferably more frequently was emphasised by Anon. (1996). The Expert Panel adopted the 95% flow duration discharge for the unregulated period at Jindabyne for each month downstream of the Mowamba River junction to include natural runoff from the Mowamba River following decommissioning of the Aqueduct and recommended that a minimum discharge of 2.3 m^3/s be adopted between Jindabyne Dam and the Mowamba junction (Anon. 1996). The 95% flows ranged from 2.2 to 27.8 m^3/s depending on the month and greatly exceed the maximum release specified in the original licence of 0.57 m^3/s. The purpose of decommissioning the Mowamba Aqueduct was to return some natural daily flow variability to the Snowy River (Anon. 1996).

River reaches

River reaches are homogeneous lengths of channel within which hydrological, geological and adjacent catchment conditions are sufficiently constant to produce either a uniform morphology or a consistent pattern of alternating morphologies (Kellerhals et al. 1976; Erskine 2005). The classification scheme of Erskine et al. (2001) has been adopted for the Snowy River. Nine river reaches are mapped in Figure 1 and described in Table 1, which also summarises post-regulation channel changes documented by published work. River types are also included in Table 1. Figure 2 shows that the reaches exhibit consistent slopes and that reach boundaries usually coincide with abrupt breaks in slope. Bedform terminology in Table 1 follows Grant et al. (1990).

River reaches are appropriate spatial units for flow management, monitoring of river condition and determining channel changes as part of an adaptive management framework (Stanford et al. 1996; Erskine et al. 2001). The same reaches were also adopted for determining river response to the new environmental flow regime (Rose 2017).

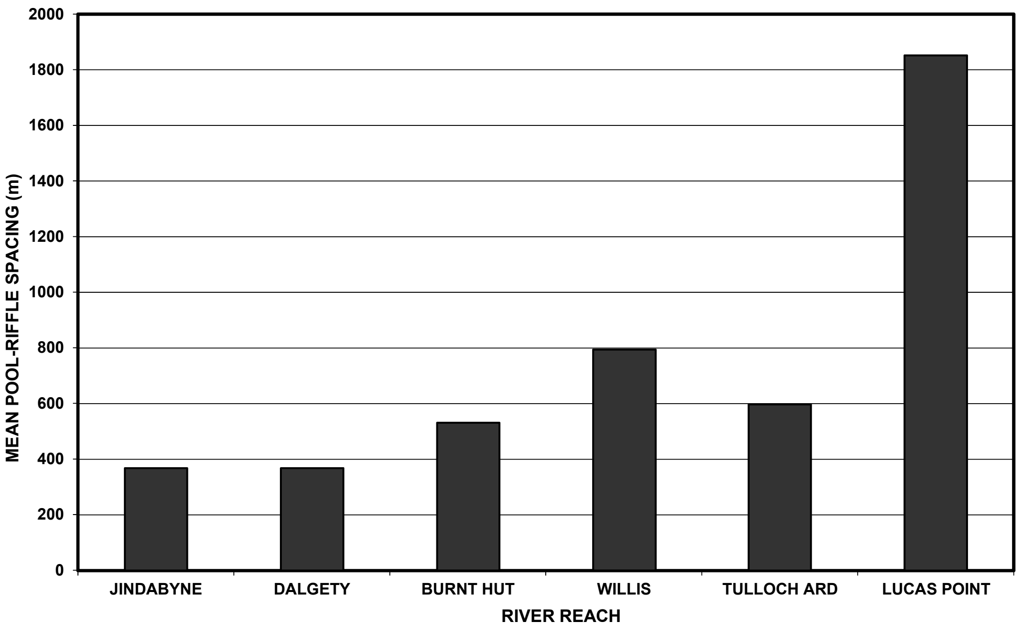

Figure 3: Mean pool-riffle spacing for the six upstream river reaches on the Snowy River contained in Table 1 and Figures 1 and 2

Bedforms

Bedforms were mapped for the 352.5 km of the Snowy River downstream of Jindabyne Dam from pre-2000 vertical air photographs (Webb & Erskine 2000). Dates of the photographs ranged from February 1994 to February 1998 and ranged in scale from 1:20,000 to 1:25,000. The length of every distinct bedform was measured to construct a complete longitudinal sequence (Webb & Erskine 2000). This paper is restricted to the 303 km covering the six upstream reaches (Figure 1 and Table 1).

According to the velocity reversal hypothesis (Leopold et al. 1964), pools are sites of flood scour and riffles are sites of flood deposition. Flood suppression should therefore result in the infilling of the upstream end of pools provided there is a source of sediment. Erskine et al. (1999a; 1999b; 2001) reported channel contraction, particularly at riffles and pool infilling on the Snowy River downstream of Jindabyne Dam. Figure 3 shows the mean pool-riffle spacing for the six upstream reaches. As expected, there is a trend of increasing pool-riffle spacing with catchment area, with the exception of the Tulloch Ard Gorge. This gorge is eroded into very resistant rocks (Orth et al. 1993; 1995) and hence is constrained from readily adjusting to discharge.

Pool-riffle spacing in the late 1990s ranged between 6.7 and 16.2 bank-full channel widths and hence was greater than the 5-7 channel widths commonly reported in the literature (Leopold et al. 1964; Richards 1982). This is not surprising because the channel did not reach a new equilibrium condition adjusted to the post-Scheme discharges. Further channel contraction and pool infilling would have occurred if the releases from Jindabyne had not been increased so that more frequent greater flood scour was re-introduced. Pool-riffle spacing is directly related to channel width (Leopold et al. 1964) but channel width is directly related to bank-full discharge (Leopold et al. 1964; Richards 1982). Therefore, bank-full discharge indirectly controls bedforms. Figure 4 shows that the mean annual flood

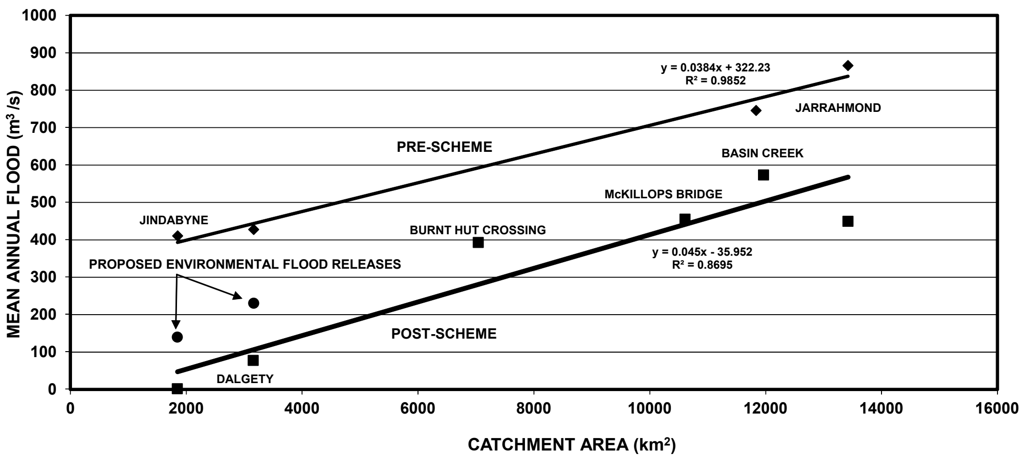

Figure 4: Least-squares linear regression equations for the mean annual flood-catchment area relationships before and after flow regulation of the Snowy River by the Snowy Mountains Hydroelectric Scheme. Mean annual flood is the mean of the $\log_{10}$-transformed annual maximum flood series.

(antilog of mean of the $\log_{10}$ of the annual flood series) on the Snowy River downstream of Jindabyne Dam has been greatly reduced by flow regulation at every gauging station. The regressions were performed on the data of Erskine et al. (1999a) with the addition of the post-Scheme data for the Burnt Hut Crossing and McKillops Bridge gauges and with the adoption of the maximum release from Jindabyne specified in the operational licence. The increase in slope of the regression for the post-Scheme period indicates that the rate of increase in mean annual flood with catchment area is now greater, as expected. Similarly, the large reduction in the y-intercept value indicates that the upper catchment has been effectively removed as a generator of flood discharge. Indeed between 1967 and 2000 Jindabyne Dam only spilled twice in October and November 1974 and 1975 when the flood gates on the spillway were tested. The rate of channel adjustment to such large-scale flood suppression will vary with the degree of bedrock confinement of the channel boundary and the amount of sediment supplied to, and stored in, the channel and available for subsequent fluvial redistribution (Erskine 1996b).

The least squares linear regression of 1990s pool-riffle spacing (*PRS*) on mean annual flood (*MAF*) is:

$$PRS = 0.5703\ MAF + 371.27 \qquad (1)$$

It is significant at $p = 0.03$. Applying the recommended mean annual floods from the Expert Panel (Anon. 1996) to this equation and allowing for downstream flood routing and tributary inflows, yields increases in pool-riffle spacing of between 3 and 294 m between Jindabyne and McKillops Bridge but a predicted decrease in the Lucas Point Reach. This decrease is highly unlikely because the pools and riffles are largely structurally controlled (Table 1). Therefore, the fully implemented Expert Panel's (Anon. 1996) recommendations should produce increased pool scour and a reversal of long-term contraction. Recent monitoring shows that this has been the case in response to the new environmental flow regime (Rose 2017).

Stratification

Although Lake Jindabyne thermally stratifies each year between about October and April, and hypolimnetic dissolved oxygen saturation progressively declines until the autumn overturn (Turner & Erskine 2005; Bowling 1993; Bowling et al. 1993; Kinross & Acaba 1996; Maini et al. 1996), our monitoring has shown that the former siphon outlet ensured that releases closely matched epilimnetic water quality in the lake. As a result, there were no cold anoxic releases.

Turner & Erskine (2005) reported strong thermal gradients with well-developed oxygen stratification and anoxic conditions below the oxycline which varied in depth from 2.75 to 4.25 m in deep upland pools for 50 km below Jindabyne Dam during warm weather (Figure 5). Continuous data-logging of water quality near the surface and near the bottom for continuous 24 h periods demonstrated that the strong thermal gradients and oxygen stratification persisted throughout the day and night (Turner & Erskine 2005).

Oxygen stratification with hypolimnetic anoxia was only recorded where the remnant pools were deeper than 4 m during summer baseflows. Depth is an important control on the development and persistence of stratification in weir pools on the Nepean River (Turner & Erskine 1997a; 1997b).

The upper reaches of many barrier estuaries in East Gippsland were strongly salt, oxygen and reverse thermally stratified during very low freshwater inflows in May 1998 at the time of the Snowy Water Inquiry (Anon. 1998). Estuary fishermen often referred to catching 'warm Southern Bream' (*Acanthopagrus butcheri* Munro) at that time. This was not surprising because the water temperatures at that time below the halocline, where the bream were caught, were up to 6.6 °C warmer than surface waters. Autumn mixing was inhibited by the very high salinities below the halocline at the head of the estuary and the very low freshwater inflows. A thin, usually 0.25 m deep, freshwater lens was present above the halocline throughout the upper 5 km of the estuary which were not investigated in earlier studies (Hinwood & McLean 1999a; 1999b; McLean & Hinwood 2015). The thin freshwater inflow had a salinity of 0 ppt but the upper estuary at the limit of tidal influence (1 km upstream of the Princes Highway Bridge at Orbost on the Snowy estuary) had measured salinities below the halocline of up to 21.6 ppt. A minor fish kill occurred in the upper Snowy estuary where bottom anoxia developed at that time, but not in other nearby estuaries (Cann River/Tamboon Inlet and Genoa River/Mallacoota Inlet) (Erskine et al. 1999b). Figure 6 shows the highly stratified conditions that existed in the upper Snowy estuary at Orbost on 3 May 1998. The oxycline and halocline were generally coincident at between 0.25 and 0.5 m below the surface in the upper 5 km of the Snowy estuary but bottom anoxia was only well developed in the upper estuary. Further downstream, the estuary was not oxygen stratified and the halocline deepened to a consistent depth of 0.5 m. Following a major flood in June 1998 (Erskine et al. 2017), the estuary was well mixed to the mouth.

Destratification

The Richardson Number (*Ri*) is used to predict the stability of stratification and is the ratio of the stabilising forces of density stratification to the destabilising effect of velocity shear (Christodoulou 1986; Horne & Goldman 1994; Western et al. 1996; Dyer 1997). Due to practical problems of measuring density and velocity gradients, the layer Richardson Number was used by Dyer (1982) to determine whether mixing will occur in estuaries when only the surface layer is moving in relation to the bottom layer. The layer Richardson Number (Ri_L) is:

$$Ri_L = \left(\frac{\delta\rho}{\rho}\right).g.D/U^2 \qquad (2)$$

where $\delta\rho$ is the density difference between the surface and bottom layer, ρ is water density, g is the gravitational acceleration constant and D is the depth of the surface layer flowing with a velocity U, relative to the deeper layer (Dyer 1982; 1997).

Dyer (1982) found that fully developed mixing (i.e. complete breakdown of density stratification) occurred at $Ri_L < 2$, that mixing was increasingly active for $20 > Ri_L > 2$ and that turbulence was ineffective in breaking down density stratification at $Ri_L > 20$. Christdoulou (1986) re-examined the literature on interfacial mixing in stratified flows and proposed four different power equations for different ranges of the Richardson Number.

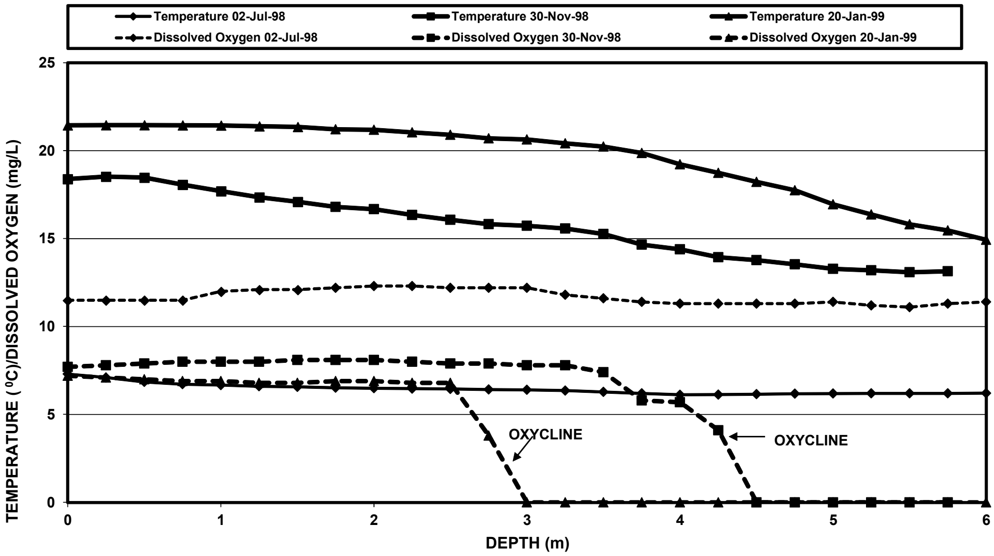

Figure 5: Examples of thermal and oxygen profiles in a remnant pool at Benchmarking site 2 (Figure 1). Isothermal conditions existed on 2 July 1998 but there were strong thermal gradients on 30 November 1998 and 20 January 1999. Anoxic conditions were present below the oxycline for the two summer profiles.

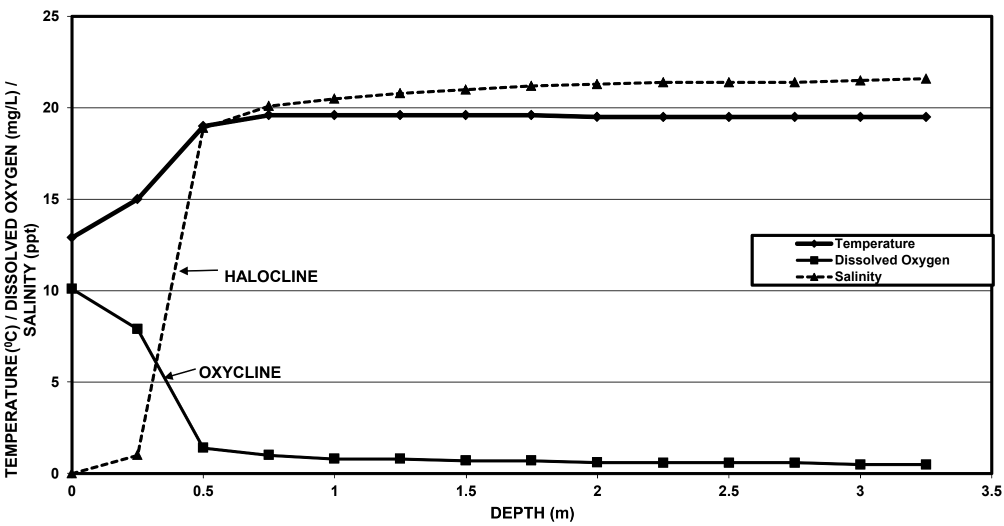

Figure 6: An example of salt, oxygen and reverse thermal stratification that was measured in the Snowy River estuary at the Princes Highway Bridge (Orbost) on 3 May 1998.

Density profiles were calculated from the thermal and salinity depth profiles because they are required as inputs to the layer Richardson Number calculations. Figure 7 shows three profiles for benchmarking site 2 and demonstrates that when strong thermal gradients were present in the Jindabyne Gorge density increased by up to 0.86 kg/m^3 from the surface to the bottom. On the other hand, density differences above and below the halocline in the upper estuary on 3 May 1998 were very large (Figure 8). Clearly the salinity differences greatly compensated for the reverse thermal stratification, producing a density difference of 14.87 kg/m^3. This indicates that much higher flows are required to effect destratification in the estuary than in the Jindabyne Gorge (Turner & Erskine 2005).

The approach adopted to calculate layer Richardson Numbers was to investigate well gauged reaches where discharge was measured at gauging stations. Detailed depth profiles of various water quality parameters undertaken at multiple sites were used to identify temporary and/or seasonal pycnoclines. This permitted the accurate specification of epilimnetic flow depth. Detailed observations of zones of slackwater, wind lanes and reverse currents under a range of streamflows and wind conditions were made at each site. This enabled the calculation of mean cross-sectional area of active flow (A):

$$A = W.D \qquad (3)$$

where W is average active flow width and D is mean epilimnetic depth. The continuity flow equation was then manipulated to calculate mean flow velocity (U) at each site for each day of measurements:

$$U = Q/A \qquad (4)$$

where Q is discharge. This was necessary because attempts to measure flow velocity with a current meter were unsuccessful because of the very low values and because a strain gauge could not be obtained for field work. Dyer (1982) concluded that mixing characteristics are better parameterized in terms of bulk flow properties than local gradient values at the pycnocline which may indicate an apparently more stable stratification. Christodoulou (1986) demonstrated the appropriateness of using mean flow velocity as the velocity measure irrespective of flow type and noted that it is the simplest to estimate. The estimated mean flow velocities during field measurements ranged between 0.002 and 0.019 m/s. The calculated epilimnetic mean flow velocity and densities were then used to determine the layer Richardson Number at each site.

The layer Richardson Number predicts that rapid destratification ($Ri_L < 2$) requires relatively small flows in the Jindabyne Gorge (<10 m^3/s) and that slower destratification ($Ri_L < 20$) requires relatively minor flows (<4 m^3/s). The Expert Panel's (Anon. 1996) recommended mean daily flows for at least 8 months of the year will ensure that pools generally do not stratify. While larger flows are required to cause destratification in the upper estuary when it is salt stratified, these flows are still relatively small for such a large river (20-30 m^3/s). The Expert Panel's (Anon. 1996) recommended annual flood of 139 m^3/s at Jindabyne and at least 2315 m^3/s at Dalgety would cause mixing and destratification of the estuary, if unregulated tributary inflows compensated for downstream routing effects. Furthermore, if larger releases are maintained from Jindabyne Dam, it is likely that salt wedge penetration into the upper estuary (Erskine et al. 1999b; 2001; Turner & Erskine 2005) will not occur in future.

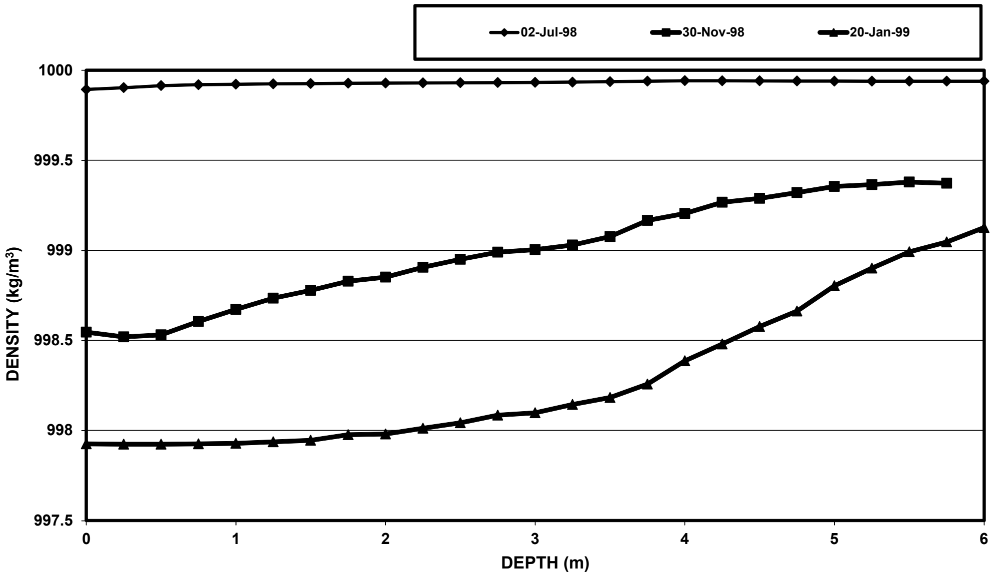

Figure 7: Density profiles in a remnant pool at Benchmarking site 2 during winter isothermal conditions (2 July 1998) and during strong summer thermal gradients (30 November 1998 and 20 January 1999). For location of site, see Figure 1.

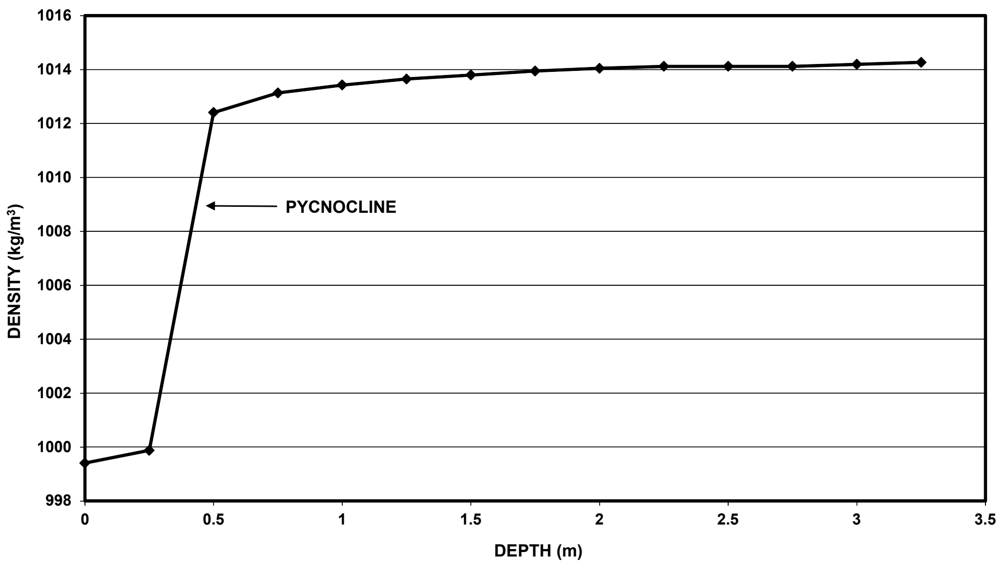

Figure 8: Density profile for the Snowy River estuary at the Princes Highway Bridge (Orbost) on 3 May 1998. See Figure 6 for thermal and salinity profiles.

Discussion and Conclusions

Hall (1989) and Harris & Silveira (1997) carried out fish habitat assessments at six sites in the lower six reaches of the Snowy River. Recommended flows for optimum habitat provision for a range of native fish species ranged from 6.9 to 11.6 m^3/s in the reaches above the estuary (Hall 1989). The proposed minimum flows by the Expert Panel (Anon. 1996) alone will meet these targets for 6 months of the year. Allowance for tributary inflows between Jindabyne Dam and Hall's (1989) sites should result in the optimum flows for habitat maximisation being reached in most months. Clearly, environmental flows for pool destratification will also meet minimum habitat requirements for fish. Furthermore, the Expert Panel's (Anon. 1996) recommended annual flood will scour pools, rework riffle and run bottom sediments and hence improve fish habitat.

The essential components of an environmental flow regime should include at least channel maintenance flows that maintain the size, shape and bedforms of the channel and re-establish ecological connectivity, habitat maintenance flows that remove accumulating silt and organic detritus and destratify pools, minimum flows to sustain aquatic and semi-aquatic ecosystems within the riverine corridor, optimum flows to maximise habitat for target species and the natural seasonal flow distribution (Petts 1996; Stanford et al. 1996, Erskine et al. 1999a; Arthington et al. 2006; Poff et al. 2010). While the Expert Panel process was a rapid assessment method the recommended flows are now known to be appropriate to re-introduce scour of pools and runs, and to destratify temporarily stratified upland pools and the episodically but strongly salt stratified upper estuary (Turner & Erskine 2005). While these factors were certainly considered by the Expert Panel at the time, the degree of analysis undertaken was minimal and based on expert opinion. Synergies between panel members and agency staff can also be effective in resolving issues and determining solutions to problems.

The Snowy River case study further illustrates the major problems that arise when efforts are made to introduce an updated environmental flow regime when the issue is not covered in a legally binding licence. The message is clear that it is important to cover the major issues in the first place so that appropriate water allocations are made initially. What has happened on the Snowy River is similar to other rivers in Australia (Williams 2017) but government response has not always been forthcoming (Sherrard & Erskine 1991; Benn & Erskine 1994; Turner & Erskine 1997a; 1997b).

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Wayne Erskine's co-authors have written the following obituary: "Professor Wayne Erskine (1954–2017) graduated with a Bachelor of Arts (Hons 1) from the School of Geography, UNSW in 1979. He then completed his PhD at UNSW on "River metamorphosis and environmental change in the Hunter Valley, NSW" in 1986. Wayne worked as a Scientific Officer with the NSW Water Resources Commission in North Sydney from 1981–1986 before becoming a Lecturer/Senior Lecturer in the School of Geography at UNSW from 1986–1998. He was then employed by State Forests of NSW from 1998–2004, firstly as a Research Hydrologist, then as Senior Soil, Water and Fish Specialist based at West Pennant Hills. Wayne subsequently joined the University of Newcastle–Ourimbah as a Professor of Natural Resource Management from 2004–2011. He provided much advice on rehabilitating the hydro-geomorphology of Australia's iconic Snowy River. He finished his career as Program Leader and Principal Research Scientist at the Environmental Research Institute of the Supervising Scientist in Darwin from 2011 until his retirement in 2014. During his career, Professor Erskine supervised more than 30 Honours, 20 Masters and 17 PhD students. He published over 150 refereed journal papers, book chapters and conference papers and will be remembered as one of Australia's most influential fluvial geomorphologists."

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First characterization of Easter Island inland waters using remote sensing techniques

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Abstract

Easter Island is the farthest human-inhabited site from a continent, and due to this condition studies on it are very scarce and restricted to basic field descriptions of its coastal marine and terrestrial ecosystems. The aim of the present study is to complete a first description of Easter Island's inland waters using remote sensing techniques, specifically the GVMI index. The results revealed monthly fluctuations in water body and wet soil surface that are due mainly to rainy seasons. These results provide an interesting first step for other limnological studies in Easter Island and other sites with access problems.

Keywords: remote sensing, GVMI index, Easter Island.

Introduction

Easter Island, located in the mid-subtropical Pacific Ocean, is the farthest human-inhabited site from any continent. The island has endemic species, as well as Asia-Pacific and South American species (Fernandez et al., 2014). In terms of hydrologic conditions, it has two crater lakes (Rano Kau and Rano Raraku) and some ephemeral pools that are present during rainy periods (Niemeyer & Cereceda, 1984; Dummont & Martens 1996). The first faunal descriptions were of aquatic insects (Campos & Peña, 1973; Dummont & Verschuren, 1991), rotifers (Segers & Dummont, 1993) and crustaceans (Dummont & Martens, 1996). Regarding fish species, the presence of introduced *Gambusia affinis* was reported in the mid-19th century (Baird & Girard, 1853; Magliulo-Cepriano et al., 2003; De los Ríos-Escalante, 2010). The widespread presence of crustacean species for Easter Island that probably were human introduced were described more recently (De los Ríos-Escalante & Ibáñez, 2015). In spite of these reports, there are no limnological descriptions for Easter Island, and in this context, if we consider its geographical isolation, it would be possible to do a first study using remote sensing techniques as an exploratory approach (Kondratyev & Filatov, 1999; Verpoorter et al., 2012; 2014). In this context, remote sensing techniques have been used for first observations of mountain lakes in Chilean Patagonia (De los Ríos-Escalante et al., 2013; 2016, 2017; De los Ríos-Escalante

& Acevedo, 2016a,b). The aim of the present study is to do a first ecological limnology analysis of Easter Island water bodies using remote sensing techniques, considering the access difficulties of these water bodies.

Material and Methods

Study site: Easter Island was visited between 19th and 24th September 2014, when it was sampled at three sites: Rano Kau and Rano Raraku crater lakes, located in the homonymous volcanoes and Rano Aroi plain, in a high plain with ephemeral pools and streams, (Table 1, Fig. 1). These sites are the main inland water bodies of Easter Island (Dummont & Martens, 1996; Canyellas-Bolta et al., 2014; De los Ríos-Escalante & Ibáñez, 2015). Rano Kau lake has a surface area of 0.11 km^2 and is 2-3 m deep (Canyellas-Bolta et al., 2014), whereas Rano Raraku lake has a surface of 0.09 km^2 and is 3 m deep (Dummont et al., 1998), and Rano Aroi is a high plain with approximately a flooding zone of 0.13 km^2 (Margalef et al., 2013). Each site was georeferenced using a Garmin GPS, and we also measured in situ water conductivity and total dissolved solids with a HANNA sensor.

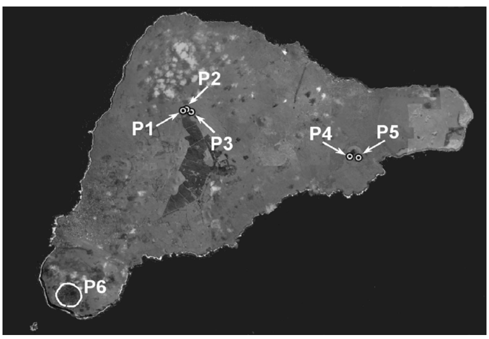

Fig. 1. Sampling monitoring of GVMI index.

Satellite information and wet index: the satellite information corresponding to ten images (Table 1), of the multispectral Operational Land Imager (OLI) sensor of LandSat-8 satellite. In the processing of the images a radiometric correction and reflectance calibration were applied, with atmospheric adjustment using software ENVI, with Flash, one of the standard MODTRAN model atmospheres and the 2-Band K-T (Kaufman & Tanre, 1992) aerosol retrieval method. After image calibration, we used the spectral index Global Vegetation Moisture Index (GVMI) for wet study (Ceccato et al., 2002; Sow et al., 2013). The GVMI was calculated from equation 1:

$$[1]\ GVMI = \frac{(\rho_{nir} + 0.1) - (\rho_{swir} + 0.02)}{(\rho_{nir} + 0.1) + (\rho_{swir} + 0.02)}$$

where ρ_{nir} and ρ_{swir} are the reflectance in close infrared bands (NIR 850-878 nm) and medium infrared (SWIR: 1556-1651 nm). The NIR and SWIR bands spatial resolution of the OLI sensor is 30 m.

Ceccato et al. (2002), define the GVMI based on an EWT (leaf equivalent water thickness), by adjusting spectral reflectance in the close and medium infrared. The index provides primarily phenological and water information, given its high sensitivity to the change of moisture content in vegetation (Sánchez, 2002; Ceccato et al., 2002; Sánchez & Chuvieco, 2000; Yang et al., 1997), whereas SWIR sensitivity is due to water presence. According to the results obtained from SWIR and NIR, it is possible to use both as effective tools to remove the vegetation influence (Ceccato et al., 2002).

Satellite monitoring: the GVMI index considered six sites where P1, P2 and P3 are located in the Rano Aroi plain, P4 and P5 are located in the surrounding of the Rano

Raraku volcano, and P6 is located inside the Rano Kau volcano. The GVMI index values correspond to mean values of areas not covered by water inside the crater (Fig. 1 and Table 1).

Results and Discussion

The results revealed that all sites have low conductivity, low total dissolved solids values and relatively neutral pH (Table 1). All sites have high levels of the GVMI index during the southern autumn and winter (April to August). The Rano Kau volcano site has a low GVMI index because it is a permanent lake with much surrounding vegetation, and with many submersed macrophytes that form a kind of vegetation island, whereas the Rano Raraku crater lagoon has intermediate values because it is a permanent lake with low littoral vegetation (Fig. 2, Table 3). A different situation was observed for the Rano Aroi sites: high GVMI index values with marked differences in seasons, with markedly low values in the southern spring-summer (September to March, Figure 2, Table 3) and high values in June, due to the rain increase in autumn (Niemeyer & Cereceda, 1984). These results agree with field observations in September 2014 (De los Ríos-Escalante & Ibáñez, 2015).

Table 1. Geographical location, altitude (m a.s.l.) total dissolved solids (mg/L), and conductivity (dS/cm), for studied sites.

	Rano Aroi 1	Rano Aroi 2	Rano Aroi 3	Rano Raraku	Rano Kau
Nomenclature at map (see fig. 1).	P1	P2	P3	P4-P5	P6
Geographical location	27° 06' 02.5'' S 109° 22' 24.3'' W	27° 06' 01.5'' S 109° 22' 21.5'' W	27° 06' 06.0'' S 109° 22' 13.0'' W	27° 07' 23.8'' S 109° 17' 26.0'' W	27° 08' 08.4'' S 109° 26' 37.9'' W
Altitude	420	402	380	90	23
TDS	0.02	0.01	0.02	0.45	0.05
Conductivity	0.04	0.01	0.04	1.17	0.11

Table 2: Satellite images used in this study. The (*) corresponds to a condition free of clouds.

Date D-M-Y	P1	P2	P3	P4	P5	P6
16th February 2014	*	*	*	*	*	*
05th April 2014	X	*	*	*	*	*
07th May 2014	*	*	*	*	*	*
24th June 2014	*	*	*	X	X	X
26th July 2014	*	*	*	X	X	*
27th August 2014	*	*	*	X	*	X
28th September 2014	*	*	*	*	X	*
14th October 2014.	*	X	*	*	X	*
15th November 2014	X	X	*	*	*	X
17th December 2014	*	*	*	*	*	*

Table 3: Results of GVMI index for the studied sites in Easter Island.

Date	P1	P2	P3	P4	P5	P6
16th February 2014	0.22	0.18	0.25	0.13	0.24	0.06
05th April 2014	No data	0.20	0.31	0.30	0.34	0.05
07th May 2014	0.28	0.21	0.32	0.31	0.33	0.08
24th June 2014	0.33	0.35	0.39	No data	No data	No data
26th July 2014	0.22	0.28	0.19	No data	No data	0.12
27th August 2014	0.19	0.22	0.19	No data	0.24	No data
28th September 2014	0.12	0.18	0.12	0.18	No data	0.02
14th October 2014	0.11	No data	0.11	0.17	No data	0.05
15th November 2014	No data	No data	0.11	0.15	0.22	No data
17th December 2014	0.12	0.14	0.17	0.14	0.27	0.01

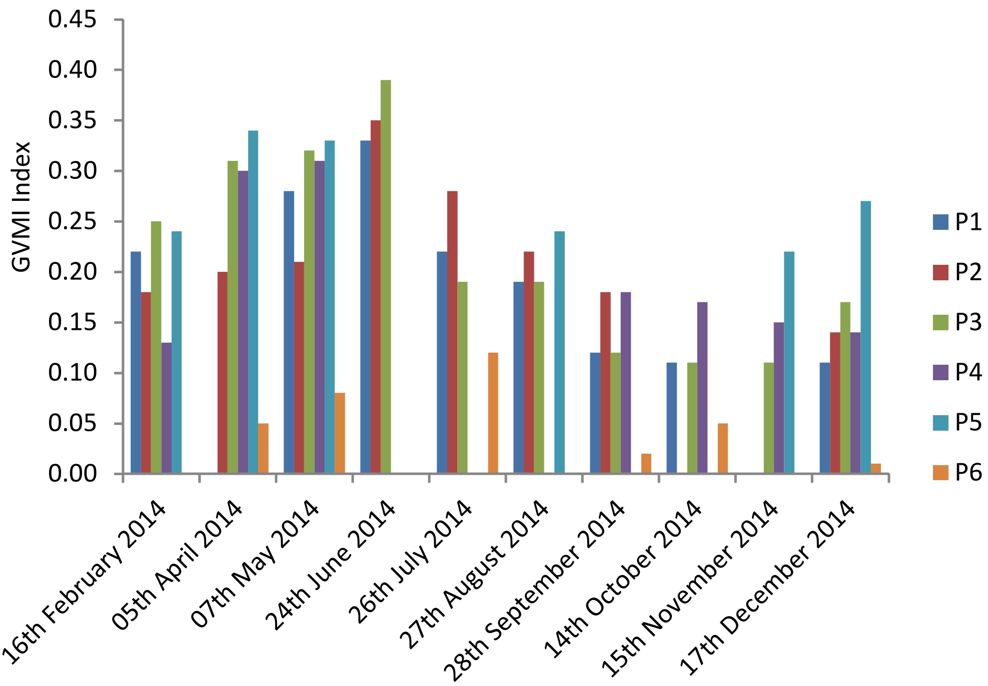

Fig. 2. GVMI index results during 2014 at six points considered in the present study.

The results would indicate that it is possible to use the GVMI index to study variations in wetlands or ecotones conformed by littoral vegetation or submerged macrophytes in shallow lakes (Nagler et al., 2013; Jarihani et al., 2014; Brooks et al., 2015; Giardino et al., 2015). From this viewpoint, these remote sensing techniques would be an important tool for basic exploration in inland waters with access problems (Mathews, 2011; Palmer et al., 2015). Moreover, if we integrated these findings, it would be possible to study variations in littoral vegetation over temporal intervals (Pérez-Luque et al., 2015).

The current literature mentions the importance of small lakes in global ecological processes (Downing & Duarte, 2009; Downing, 2010), and in these conditions it would be important to characterize and to do an inventory of these small lakes with a surface area less than 1 km^2 (Downing et al., 2006; Bartout et al., 2015). In this scenario, the use of remote sensing techniques could be useful for characterizing small lakes for inventory purposes (Verpoorter et al., 2012; 2014).

This first study could be a basis for further studies of the variations in Easter Island inland waters and surrounding vegetation communities.

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Introducing Julian Tenison-Woods and Malacca

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Abstract

In 1883 and 1884, the Australian pioneer scientist and priest, Julian Tenison-Woods, conducted geological, zoological, and geographical research in the area which is now Malaysia. The government of the Straits Settlements commissioned this research, and reports made by Tenison-Woods to the government contain some of the results. One of these reports on the geology and mineralogy of Malacca is printed in this issue of the *Journal & Proceedings of the Royal Society of New South Wales* and this short text is an introduction to Tenison-Woods' report.

The Source

The *Proceedings of the Legislative Council of the Straits Settlements* may seem an unusual place for geological reports, but we should not be surprised. We can recall that the *Proceedings* (in a similar usage as parliamentary papers in Australia) include a variety of reports and other materials which were tabled for the use of Legislative Councillors and the public. In those *Proceedings* we can find the work of one of Australia's pioneer scientists, Fr. Julian Edmund Tenison-Woods. Readers may already be familiar with Tenison-Woods as an honorary member of the Royal Society of New South Wales, who in 1888 was awarded the Society's Clarke Medal for distinguished contribution to the geology of Australia. Between 1877 and 1888, Tenison-Woods contributed fifteen papers to the Society's *Journal*, listed below.

In the *Proceedings of the Legislative Council of the Straits Settlements for 1885*, we read a series of appendices. The second of these, laid before the Council on 22 January 1885, is the *Report on the Geology and Mineralogy of the State of Malacca,* by Tenison-Woods. (Tenison-Woods, 1885a) This report is not included in the lists of Tenison-Woods' publications prepared by Sr. Margaret Press, although it is mentioned in her biography. (Press 2004, p. 210). This introduction will give background information about Tenison-Woods' visit to the Straits Settlements.

However, before proceeding, acknowledgement must be given to Mr Tim Yap Fuan of the library of the National University of Singapore, who brought this document to modern readers. Mr Tim's familiarity with the Straits Settlements' documents is evident from the speed with which he was able to find this report.

Julian Tenison-Woods, pioneer Australian scientist

Clergy were prominent among pioneer scientists in Australia. (The Royal Society of New South Wales named its Clark Medal for Anglican clergyman and geologist William Branwhite Clark, a founder of the Society.) As a young man, Julian Woods (as he was then known) had migrated from his native England to Australia, and after brief studies at Sevenhill College in South Australia — where his scientific interests were encouraged by Jesuit John Hinteroecker, who had been a professor of natural science in Linz (Anon. 1924, p. 4) — Woods was ordained as a Catholic priest. He served for ten years in rural South Australia, where he began publishing on scientific subjects. Julian is best known for his relationship with Australia's first Catholic Saint, Mary of the Cross MacKillop, whom he met in Penola, and with whom he worked in the foundation of the Sisters of St Joseph. Woods went on to be a pioneer in education as the first director of Catholic Education in South Australia, and as a founder of other religious orders. Leaving South Australia, he worked for many years as an itinerant missionary up and down the east coast of Australia and in Tasmania. Woods has been the subject of some book-length biographies and numerous journal articles (O'Neill 1929; Hepburn 1979; Doherty 1996; Press 2004). Woods himself wrote extensively, and began using the name Tenison-Woods to distinguish himself from other scientists named Woods (his mother's maiden name was Tenison), and henceforth we will use this name. After publishing a number of articles (Wilson 2011, p 30), at only thirty years of age he embarked on his first book on the geology of South Australia (Tenison-Woods 1862). His commitment to science and to publication in the journals of learned societies and in the popular press continued for the rest of his life. He was still dictating publications in his last illness. Tenison-Woods died in October 1889, honoured especially by the scientific community.

One aspect of Tenison-Woods' later work was writing reports for government. In 1881 he had reported to the Queensland Government on mining for tin (Tenison-Woods 1881). The New South Wales government had requested a book on fish and fisheries, commissioned for the Fisheries Exhibition in London in 1883 (Tenison-Woods 1883a). Further reports to government are discussed below.

From 1875 to 1880 Sir Frederick Weld, of a recusant Catholic family, was Governor of Tasmania. At this time Tenison-Woods was conducting missions for the Catholic Church, and was also researching and writing as he travelled. Weld chaired some of Tenison-Woods' public lectures, and was president of the Royal Society of Tasmania when Tenison-Woods presented his researches (Somerville 1943 p199). It is to Weld that we owe the next chapter in Tenison-Woods' life.

Julian Tenison-Woods in the Straits Settlements

For reasons beyond the scope of this paper, opportunities for Tenison-Woods to serve as an itinerant missionary became fewer in the 1880s. By this time Weld had become Governor of the Straits Settlements, and he invited Tenison-Woods to conduct a geological survey in the Straits Settlements and Peninsular Malaya. Tenison-Woods accepted this invitation, and in mid-1883 began the journey to Singapore. On the way, the Queensland government commissioned a report on coal resources (Tenison-Woods 1883b; Tenison-Woods 1883c). His journey, assisted by letters of introduction from Weld, took Tenison-Woods through what is now Indonesia, and in October 1883 he arrived in Singapore.

Weld left for a visit to England, where he found time to address the Royal Colonial Institute. Describing the geography and geology of peninsular Malaya, Weld remarked: "The exact facts will be reported on by the Rev. Julian Tenison-Woods, a well-known geologist, who has just visited the district on behalf of the Perak Government" (Weld 1883-1884, p266).

Tenison-Woods soon embarked on a preliminary journey north, returning to Singapore in time for Christmas, 1883. During 1884, he continued his research, which generated a number of scientific papers. One of these was the report on Malacca reproduced below. Another was the report on Perak, which Tension-Woods also published in Sydney (Tenison-Woods 1885b). Some of his later travels included a voyage on *HMS Pegasus*, and it was on *Pegasus* that in 1885 he was able to visit Labuan and Brunei. The results of his observations on coal were published in England (Tenison-Woods 1885c). Soon after, Tenison-Woods had the opportunity to travel on *HMS Flying Fish*, then conducting surveys in south-east Asia, planning to return ultimately to Australia. Changes of plan along the way meant that Woods did not return to Australia until June 1886, when he disembarked in Darwin.

The scientific output of Julian Tenison-Woods

Reports for government were an important part of Tenison-Woods' scientific output. Here we have a report from his work in Malacca made available to modern readers. After his return to Australia, he continued to accept government commissions. In 1886 he reported to the government of South Australia on the geology of the then Northern Territory of South Australia (Tenison-Woods 1886). Perhaps other reports might again become available, including a report on coal which was mentioned in one of the notices of his death (Anon. 1889, p 6). Besides reports, Tenison-Woods also wrote regularly for the popular press and gave interviews on scientific topics. He was respected for his ability to articulate his scientific knowledge for a general audience.

Nevertheless, at the heart of his scientific output we find lectures and papers for learned societies. Without a university degree, Tenison-Woods, like many of his contemporary scientists, found his membership of learned societies provided validation of his work, and a congenial company of largely amateur scientists. While Tenison-Woods contributed most to the Linnaean Society of New South Wales, and served as its president, he contributed to other learned societies (King 2016, p 49.) Honorary memberships also served him well, providing opportunities for his interaction with knowledgeable scientists. In the Straits Settlements he became an honorary member of the Straits Branch of the Royal Asiatic Society, and published in the branch's journal. We can conclude by recalling his status as an honorary member of the Royal Society of New South Wales, and as a frequent contributor to its journal.

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Appendix

A list of the contributions by Fr. Julian Tenison-Woods to the Royal Society of New South Wales:

"On the Tertiary deposits of Australia" (1877) *JProcRSNSW*, 11: 65-82.

"On some new Australian polyzoa" (1877) *JProcRSNSW,* 11: 83-84.

"The palæontological evidence of Australian Tertiary formations" (1877) *JProcRSNSW*, 11: 113-128.

"On some Australian Tertiary corals" (1877) J*ProcRSNSW*, 11: 183-195.

"Tasmanian forests: their botany and economical value" (1878) *JProcRSNSW,* 12: 17-28.

"The molluscan fauna of Tasmania" (1878) *JProcRSNSW,* 12: 29-56.

"On some Australian tertiary fossil corals and polyzoa" (1878) *JProcRSNSW,* 12: 57-61.

"On the anatomy of *Distichopora*, with a monograph of the genus" (1879) *JProcRSNSW*, 13: 49-63.

"The Hawkesbury Sandstone" (1882) *JProcRSNSW,* 16: 53-116.

"On some carboniferous marine fossils" (1882) *JProcRSNSW*, 16: 143-145.

"On some Mesozoic fossils from the Palmer River, Queensland" (1882) *JProcRSNSW*, 16: 147-154.

"A fossil plant formation of central Queensland" (1882) *JProcRSNSW*, 16: 179-192.

"On the Wianamatta shales" (1883) *JProcRSNSW*, 17: 75-85.

"On the anatomy and life history of Mollusca peculiar to Australia" (1888) *JProcRSNSW*, 12: 106-187.

"The desert sandstone" (1888) *JProcRSNSW*, 12: 290-335.

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Report on the geology and mineralogy of the State of Malacca

By the Revd. J. E. Tenison-Woods, FGS, &c.

Abstract

In compliance with a request from His Excellency Sir Frederick Weld, previous to his going to England, that I should visit and report on the geology of Malacca and the neighbouring states, I visited Malacca in October, 1884. The following is the result of my brief examination of the Malacca territory.

Report[1]

The geology of the State of Malacca is of a very simple character. It consists of low hills of palæozoic strata with occasional outcrops of granite and a small amount of overlying beds of alluvial.

The minerals found in these rocks are gold, tin and iron.

I shall briefly consider the above formation in detail, in the order in which they are named.

Palæozoic Rocks

This formation consists of highly inclined ferruginous slates, schists and gneiss, with occasional veins of quartz. On the surface it weathers into a red honeycombed rock not like [sic] a decomposed volcanic ash. Possibly some of it may be volcanic, but of great antiquity, as, for instance, Bukit China, where the volcanic character seems marked. There are other places where the wearing and weathering of the ferruginous rocks have affected the underlying granite, which now alone remains. The partly decomposed granite then appears as a brown mass with white crystals of felspar scattered through it.

The formation is distinctly stratified, the strata being highly inclined, and occasionally quite perpendicular. There are numerous bands and partings of slate, chert, marly rubble, and green sandstones with mica. The general appearance of the deposit strongly reminds one of the palæozoic or Ordovician rocks of Victoria and New South Wales in Australia, which have proved to be so extensively and richly gold-bearing. I think it highly probable that the beds are of the same age, more especially as from time immemorial these Malacca strata have been worked for gold. There are true quartz veins amongst them and one at the foot of Mount Ophir has been worked quite recently by an English company.

I was never able to examine a section showing the actual junction of the palæozoic rocks with the granite, at least in the Malacca territory. The possibility is that the passage from one rock to another is gradual and manifests metamorphism. I should think that this has taken place after the upheaval of the slates to their present perpendicular position.

Without an accurate survey, it is impossible to say what the thickness of these beds may be. They are doubtless repeated in successive folding, as their present perpendicular position is due to lateral pressure. The formation itself is not very thick, as the granite is, in numerous places, quite close

[1] Reprinted from Appendix 2 in the *Proceedings of the Legislative Council of the Straits Settlements for 1885*, January 1885.

to the surface. In all such localities, tin may be looked for in small quantities.

The palæozoic rock is largely mixed with poor iron ores, and where the surface water charged with carbonaceous matter has come into contact with these ores, they have been oxydised [sic] and converted into a red and reddish-brown limonite called here laterite.

This laterite has been a geological puzzle to most of those who have written on the geology of the Malayan Peninsula. It is remarkable what a variety of guesses have been hazarded as to its origin. Some writers who have pretended to offer an explanation seem purposely to have obscured their meaning from inability to deal with the difficulty. It has been called volcanic, and regarded as a tertiary outpouring of basalt, and so forth. As already stated, the real character of the stone is simply due to the oxydation [sic] of a ferruginous series of rocks. The formation which has mostly supplied the materials for the laterite is the stratified palæozoic slates and the granite in contact with them. It is a decomposed rock. Water and air have been the decomposing agents.

It is a most significant fact that there is no evidence whatever of recent upheaval from the sea, or even marine action. It would be hardly possible for this laterite or limonite with silicates of iron to be in course of formation without entombing some marine remains had they been in contact with them. Malacca is no exception to the general rule throughout the Malayan Peninsula that there is no evidence of recent upheaval in all the great extent of its coastline.

Granite

The granite is of the usual grey colour of the granites which form the main axis of the Malay Peninsula. It seems in every respect to have the same mineral character. There is every reason to believe that it is an altered stratified rock of the same character as the granite in Perak, and probably possessing similar metals, such as tin, gold and iron.

Alluvial

The alluvial is the result of surface weathering. Water-worn drifts are not common in the Malacca territory. Whatever decomposition has taken place has, for the most part, remained in its original position.

This fact has an important bearing on the way in which a search should be made for the minerals contained in the rocks. An explanation will be given further on.

Physical Geography

If we suppose Mount Ophir to be outside the boundaries of the territory of Malacca, there are no high mountains within its limits. The whole of the State may be said to consist of undulating hills of very moderate elevation and having generally a trend in the direction of the main axis of the peninsula. A few streams of small importance drain into the Straits of Malacca to the westward, as the land is on the western watershed.

The hills are, no doubt, outliers of the main range. Their character will be better understood if it be borne in mind that the main range, which forms the backbone of the Malayan Peninsula, gradually declines after reaching its culminating point in the high mountains of Perak and Pahang. About the latitude of Malacca, not only does the range decline, but loses its continuity. To the south and east of Malacca, there are places where the watershed of the peninsula is, with difficulty, determinable. The range becomes broken up into isolated groups of mountains. Of this, Mount Ophir is one. It does not belong properly to the territory, nor is the country affected to any extent by its proximity, so that

I do not include it in its physical features. It is the highest mountain in this part of the peninsula but very much below the mountains of Perak and Pahang. It is isolated and not accompanied by any great elevation of the main range in its neighbourhood. Thus there is not extensive drainage passing through the Malacca territory, and consequently no large deposit of alluvial matter on the surface.

Now, bearing in mind these features, it is easy to arrive at the general conclusions as to the mineral resources of the Settlement, and what are the probabilities of any extensive development of the mining industry.

Observations in other parts of the peninsula have shown me that the stream tin deposits are alluvial and that they are found in the greatest quantity in the junction of the granite with the palæozoic schists, slates, and gneissose rock already referred to. The absolute amount of tin at this junction is probably not great, but when it accumulates under the influence of alluvial washing from the weathering of the rocks, it becomes considerable. Thus, if the laterite or red rock were washed at its junction, or near to its junction, with the granite, it would not yield tin enough to pay for the labour. Some tin will be found, but not enough to pay for the mining. It requires the operation of nature's laboratory, or mechanical terrestrial forces, to produce the deposits of sufficient extent to remunerate regular working as a mine. What is needed is the weathering influences of streams acting upon large surfaces of rock and acting upon them during long periods of time. By these means, the matrix is worn down and reduced to the finest sub-division. The lighter particles are carried away by the streams, whose waters are then rendered turbid. They are deposited as sediment on the coasts: on mud flats which accumulate to such a considerable extent on the shores of the Straits of Malacca. This tin, by its weight, remains behind, being sifted and mingled with coarse gravel.

It can be easily perceived that the higher the mountains, the more extensive the drainage and consequent weathering. This action is also more rapid. Thus all the most valuable of the tin mines in the neighbourhood of the Straits Settlements are found in those parts of the peninsula which are very mountainous, and where the mountains are both high and steep. While, therefore, I think that probably there is as much of the tin-bearing rocks on the territory of Malacca as in any part of the peninsula, I must add that, owing to the moderate elevation of its mountain system, at present, there are no surface indications of sufficient alluvial deposit to give prospects of rich accumulations of stream tin. Deeper deposits there may be, as I shall explain further on.

The preceding conclusions will show where the ore deposits are to be looked for. These are:- on the slopes of mountains, by the sides of streams, or in their ancient beds and especially where the granite crops out at the junction of the palæozoic rock.

Mines in the Territory of Malacca

Besides the many localities where the sand is washed by a few Chinese for the small quantity of tin which it contains, there are two or three places only where more extended mining operations are carried on.

Linggi Sands

As an instance of the small operations of Chinese sand-washing, I may mention that of Linggi. A little to the south of the river of that name, at a distance of a mile or so, a few Chinese gain a precarious subsistence on the sea-shore, by washing the sand for tin at low tide. The quantity obtained is small, and in the form of coarse, rounded grains of cassiterite. The ore has this peculiarity that the grains are not of a generally uniform size, but of a mingled character, large and small together. I attribute this to the fact that the grains have not been sorted by alluvial washing, but are found in this position, just washed out by the sea from the junction of the granite and palæozoic rock. Now, at Thaipeng and other alluvial tin mines in Perak, where the sands have been subject to much silting by alluvial action, the tin ore is generally found to be sorted. Near the mountains and in the steep gullies, the tin ore is coarse, and the farther it is traced from the hills the finer it becomes. A slight experience enables one to tell at a glance what is the nature of the locality from which ore has been derived – whether near mountains or from plains, or from the sea-shore.

Panchor

At a place called Panchor, seven miles south of Linggi, there is another small area where the sand is washed for tin by two or three Chinese. The beach is lined with vesicular red rock or palæozoic slates, which have been much affected by sea water. Granite crops out close by. The amount obtained here is very small, and only to be got at low tide, the men employed scarcely make the moderate wages which will maintain a Chinese coolie.

Chin-Chin

These mines are situated near the southern boundary of the territory of Malacca, about ten miles from Mount Ophir. They are the largest tin mines in the territory, but I should think that all the country right to the foot of Mount Ophir, may reasonably be expected to produce tin. The land and the character of the mine have considerable resemblance to the Kamunting mines in Perak. The ground is very undulating. The workings are at present between the low hills. On the surface the ground is strewn with angular fragments of quartz, slate, jasper, and gneiss. The sinking is through two to three feet of black carbonaceous mould, then two or three feet of yellow, or red gravel, then 40 to 50 feet of white pipe-clay and sand, then the wash dirt or tin sand.

The surface has evidently been a swampy jungle, and there are signs of workings having been carried on for a considerable period. About 100 coolies were employed at the time of my visit.

The tin seemed of good quality in finely divided grains. From this, I should infer that it has travelled some distance. Probably other beds of coarser tin will be found nearer to the mountainous spurs of Mount Ophir. On the whole, I consider that the mineral resources of the district are decidedly promising.

At Chin-Chin itself, the great thickness of the overlying alluvial, which is 50 feet at least, must be a great drawback, but it is probable that other and shallower deposits will be found towards the mountains.

There is one consideration connected with this mine which ought not be lost sight of. When we find 50 feet of alluvial drift in one place, and under what is now a level swamp, it shows that there are immense accumulations of detritus hidden under a level surface. It shows also that there have been long periods of weathering action in the geological history of the country. This we might conclude from the enormous mud deposits along the shallow coasts and banks of the Straits of Malacca. The ore has, during past ages, largely encroached upon the land. In the alluvial action, some mountains must have been worn down, and the detritus undoubtedly must be rich in tin. This leads me to the conclusion that boring operations in some of the level marshy flats where rice is now grown may be attended with successful results, and rich deposits of tin found where hitherto it has never been looked for. It may yet be worth the while of the Government to test this question. It may be that these marshy flats represent the ancient drainage of the country, and from what little I have been able to observe, I strongly suspect that it is so.

Former historians of Malacca speak of a stream on the south side of the city[2]. This stream has disappeared, as no doubt many others have done. The tendency is of mountain drainage to become obliterated as the sources are lowered by weathering and the estuaries fill up from the sluggishness of the waters.

If my suggestions are correct not only tin may be looked for, but also alluvial gold, in the drift under the marshes.

Gading

A small mine is worked by a few Chinese on the road between Allor Gadja and Ayer Panas. The washings are exactly on the junction of some decomposed palæozoic rock with the granite at a few feet below the surface. The tin is fine, with much iron intermixed. None but the most economical methods would enable even the Chinese to work such a deposit with profit. Only about half-a-dozen men are employed.

Conclusion

The peculiarity of the geology of the territory of Malacca renders it probable that small quantities of tin are spread throughout the whole extent of the country. I am further of the opinion, that my suggestion that the marshy lands represent the former drainage of the country, must lead to an important development of the mining interests of the Colony. They are so extensively spread, and occupy so large a portion of the territory, that even if tin or gold be found in a third of them, the result must be great. I should strongly recommend that a small sum should be annually set apart for boring operations so that the ground may be thoroughly tested.

Gold: I entertain no doubt that the quartz veins of the palæozoic formation are all more or less auriferous. In ancient times we may be pretty certain that the alluvial deposits contained gold. In the more populous parts of the country this has long ago been extracted, but I think it very likely that a careful search might reveal washing stuff which would yield small quantities of gold. Like most of the gold found in connection with granite, it will probably be scaly, or else in the form of gold dust.

If prospecting be undertaken, it should be in alluvial gravels, and first of all in the upper waters and banks of small streams; as already stated, the lower portions of the streams have been well worked formerly.

For any other metals excepts gold and tin, the geological indications in Malacca are not favourable. If near a coal mine, the red rock might be valuable for iron. If the trade of the port were larger, it might even pay to export it as ballast. The iron from such ores is usually of excellent quality.

J. E. Tenison-Woods
Singapore, 30th December, 1884

[2] D. F. A. Hervey, "Valentyn's description of Malacca," *Journal of the Straits Branch of the Royal Asiatic Society*, No. 13 (June, 1884), pp. 49-74B, 260

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P. A. M. Dirac and the Maverick Mathematician

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Abstract

Historian of science Ann Moyal recounts the story of a singular correspondence between the great British physicist, P. A. M. Dirac, at Cambridge, and J. E. Moyal, then a scientist from outside academia working at the De Haviland Aircraft Company in Britain (later an academic in Australia), on the question of a statistical basis for quantum mechanics. A David and Goliath saga, it marks a paradigmatic study in the history of quantum physics.

P. A. M. Dirac (1902–1984) is a preeminent name in scientific history. In 1962 it was my privilege to acquire a set of the letters he exchanged with the then young mathematician, José Enrique Moyal (1910–1998), for the Basser Library of the Australian Academy of Science, inaugurated as a centre for the archives of the history of Australian science. This is the only manuscript correspondence of Dirac (known to colleagues as a very reluctant correspondent) held in Australia. The twenty-four letters exchanged between the two men in 1944–46 at the height of war offer an important and little known case study — a paradigmatic study — in the history of physics.

The two correspondents, despite a common engineering component, came from very different backgrounds, José Enrique Moyal (who would fetch up as Reader in Statistics at the Australian National University in 1958–1965) was born in 1910 in Jerusalem to a Jewish lawyer father and a French mother and was educated at the local Herzliya Hebrew Gymnasium in Tel Aviv. From there, unmentored, he made his way in 1927 to Magdalene College, Cambridge, to study mathematics, but facing unsupported university costs, he moved to the school of engineering at the Institut d'Electrotechnique in Grenoble, enrolling subsequently at the Ecole Supérieure d'Electricité in Paris. Trained as a civil engineer, Moyal worked for a period in Tel Aviv but returned to Paris in 1937, where his exposure to such foundation works as Georges Darmois's *Statistique Mathématique* and A. N. Kolmogorov's *Foundations of the Theory of Probability* introduced him to a knowledge of pioneering European studies of stochastic processes. In 1939 he added theoretical physics focused on the foundations of quantum theory at the Institut Henri Poincaré at the University of Paris. After secret wartime work in Paris with the French Ministry of Air, and the German invasion of France, Moyal escaped to Britain where he was posted by C. P. Snow, then in charge of Scientific Manpower, for wartime research at the De Haviland Aircraft Company in Hampshire.

Paul Adrien Maurice Dirac, by contrast, was born in Bristol in 1902, took a degree at Bristol University in engineering and graduated in 1923 with first-class honours in mathematics. With initial published research in statistical mechanics, he gained his Ph.D. in quantum mechanics in 1926, from which his classic work, *The Principles of Quantum Mechanics* (Dirac, 1930–58), led him to election to the Royal Society of London in 1930, appointment as Lucasian Professor at Cambridge in 1932 (a post he held for 47 years), and a Nobel Prize, which he shared with Erwin Schrödinger in 1933. Widely regarded as the high priest of British physics, Dirac had established the standard theory of quantum physics, his book became the bible in the field, and he was assured that his methodology was correct and his theory complete.

It was to this pre-eminent but reclusive scholar, an academic known for ignoring the work of upcoming younger men (Farmelo, 2009), that J. E. Moyal, a British citizen of the Mandated Territory of Palestine, a researcher from outside academia, applied by letter on 18 February 1944 with his controversial idea of the possibilities of a statistical basis for quantum mechanics and a method to make the connection of classical mechanics to quantum mechanics in phase space. He found the professor in receptive mood. "I should be glad to meet you any weekend," Dirac replied on 22 February, "so choose any weekend you like." Their meeting on 11 March 1944 at Dirac's house in Cavendish Avenue, Cambridge, however, apparently brought the professor little joy. As his biographer, Helge Kragh, writes, Dirac "did not consider the probabilistic interpretation as something inherent in the quantum mechanical formulations" (Kragh, 1999).

But, undeterred, on 26 June 1944 Moyal returned to the task.

> On thinking over the objection you raised when I last saw you to my statistical treatment of quantum mechanics, [he wrote] it has occurred to me that the difficulties are chiefly a question of interpretation… As I explained in my paper, I consider the form I obtained for the phase-space distribution $F(p,q)$ as in a way of extension, or rather an exact form of Heisenberg's principle of uncertainty.

Sketching out his mathematical formulation carefully, he posited that, in fact, the dynamical problems the two had discussed offered "one case where the methods I have outlined may have advantage over the usual method." The theory led, in Moyal's view, to the distribution of phase space and also to correlations at two instants of time where, he suggested, "there is a possibility that it may lead to experimental verification in the field of electron and molecular beams." "Another field where I think the theory may be of some value," he added, "is in the study of statistical assemblies, since it leads to phase-space distributions for p and q, for Fermi-Dirac and Bose-Einstein assemblies."

Dirac, however, remained silent. When he wrote again some nine months later, on 19 March 1945, he had slightly ameliorated his negative view and indicated that work he had been doing had caused him to think there might be "a limited region of validity for the use of a joint probability distribution" in Moyal's work. Seeking a copy of the paper, he conceded, "I may get a more favourable opinion of it this time." Responding on 22 March 1945, Moyal referred Dirac to Maurice Bartlett[1] who had "worked out a new and improved method of obtaining a joint distribution" and noted that, in collaboration with Bartlett, he himself had also "carried further the treatment of the harmonic oscillator in phase space" (Bartlett and Moyal, 1949). "I also [he added] have been considering applications to statistical

[1] Maurice Bartlett had studied statistical mechanics with R. H. Fowler and physics with Dirac at Cambridge. He became a leading figure in Britain in statistical mechanics and probability theory.

mechanics which, since they require distribution in phase space, would seem to offer an obvious field for the theory."

Dirac's reply a month later, on 20 April 1945 (for both men were engaged in demanding wartime work, Moyal researching the mathematical character of complex systems, electronic instrumentation and the theory and practice of space vibrations and waves needed in the wartime aircraft industry, and Dirac importantly for the government on uranium separation relating to the construction of atomic bombs), was less than encouraging. He did not believe that the phase-space approach offered anything significant outside his own established formulation. Clearly satisfied with this dismissal and committed to his own interpretation of non-commuting observables in the paper he was preparing for *Reviews of Modern Physics*, he proposed to refer to Moyal's work in broad terms. "The possibility of setting up a probability for non-commuting observables in quantum mechanics to have specified values," he set down, "has been previously considered by J. E. Moyal… but its region of applicability is rather restricted and it does not seem to be connected with a general theory of functions like the present one."

Moyal's letter in reply on 29 April 1945 was robust. "I do not think that your reference to my work gives a correct description of it," he wrote (for Dirac, it appears, was confusing commuting p and q variables with non-commuting operators, P and Q). And unintimidated by his contester, he went on: "This would perhaps not matter a great deal if my work was already published, since readers could then refer to the original. I have not however been able so far to arrange for its publication, due largely as you will no doubt remember, to your veto which made the late Professor Fowler hesitate about presenting it to the Royal Society." As an outsider pinning his hopes of a research career on his research achievement, Moyal's frustration was real, since he believed that his reply to the dominant physicist had presented his reservations satisfactorily. "The papers you have seen," he now told Dirac, "represent my first real effort at research in pure mathematics and theoretical physics; I was hoping that their publication would eventually enable me to transfer my activities entirely from the field of engineering and applied physics to that of pure science. …Failure to obtain publication has forced me to adjourn such plans *sine die*."

The mathematician from outside academia had run up against an entrenched paradigm. As the most esteemed figure of quantum mechanics in Britain, Dirac's position within the discipline was set in stone. At Cambridge, he had always conducted his research on his own, in marked contrast to his eminent European colleagues who enjoyed the advantage of both formal and informal collaboration. Moreover, from his earliest endeavours, he was introspective and tenacious in his confidence in his own views. With sixty-four published papers behind him in 1945 and his foundation book, he appeared, as both Kragh and the distinguished Australian mathematician, Alan McIntosh, characterised him, as "intellectually incapable of, and unwilling to give ground" (McIntosh, 2003).

The David and Goliath struggle would continue across two more months. In his letters of 11 and 18 May 1945, Dirac again resisted Moyal's position and attempted to show that his argument was trivially wrong. But, stirred perhaps by Moyal's charge over publication, he went so far as to suggest: "I would be willing to help you publish if you would change it [the presentation] so that it does not contain any general statements which I think to be wrong."

Such surrender was not acceptable to the independent Moyal. His forthrightness owed something to his 'Israeli' background. He would not be cowed. Born in Palestine in the last decade of the Ottoman Empire, Moyal belonged to no particular nation but, as the region's history unfolded, he deemed himself an 'Israeli'. "Summarizing," he concluded in his letter to Dirac of 15 May 1945, "I think it would be fair to say that my paper gives a derivation of classical quantum mechanics on a purely statistical basis (plus Newtonian mechanics) which is equivalent to the standard matrix theory… and furthermore that it shows the consequences such a theory entails with regards to the problem of determinism, probability distributions, fluctuations, quantum statistics." He would affirm his position even more firmly in his subsequent letter of 26 May 1945:

> I don't think [it read] your remark on [my] getting the right answer 'by borrowing sufficient results from the ordinary quantum theory' quite fair. In so far as my theory is equivalent to the ordinary theory, it leads to the same eigenvalues for the mean of the energy, as I have shown in my paper. In order to prove an inherent inconsistency in my theory one would have to show that the method you use follows necessarily from my basic postulates, and this is not the case. My method on the other hand is based on a theory for statistical assemblies resulting from these postulates. As such it is quite consistent with the rest of the theory, and also appears to lead to correct results.

To little avail. Despite Moyal's objection to its contents, Dirac made no change in his original reference to his discussant's work in his *Reviews of Modern Physics* paper of 1945 although, in a rare reference to a contemporary researcher, he went so far as to allow: "This work is not yet published. I am indebted to J. E. Moyal for letting me see the manuscript." Dirac, however, had made one positive recommendation. If Moyal wrote the quantum theory part of his work in a separate paper, he himself could communicate it to a scientific journal. More controversial communication lay ahead, but, in July 1945, Moyal was notifying Dirac, that, as suggested, he was "rewriting the part of my paper on quantum mechanics as a separate paper."

Moyal's, 'Quantum Mechanics as a Statistical Theory' was at last submitted to the Cambridge Philosophical Society from his first academic post at the Department of Mathematical Physics, Queen's University, Belfast, in November 1947 and published in their *Proceedings* in 1949 (Moyal, 1949a). A second section of his manuscript was published as his paper, 'Stochastic Processes and Statistical Physics', in the *Journal of the Royal Statistical Society* (Moyal, 1949b) that same year. But as he affirmed privately in later years, "my first paper really contained all the essentials of the formalism, the version of quantum which is an equivalent of older mechanics" (Moyal A., 1979).

'Quantum Mechanics as a Statistical Theory' proved to be a research contribution far ahead of its time. Received initially by a small range of researchers in quantum fields, it made quiet headway while the fundamental formalism it presented in the 'Moyal bracket', the 'Moyal formula' and 'Moyal plane' (phrases that indicated non-commutativity) flowed into the lexicon of physics from the 1960s, gathering range and currency as the international research community grew. It was not, however, until the new century that the paper burst into high prominence and came to underlie an explosion of research in quantum physics and related fields that stretched from string theory, atomic and molecular systems and quantum chaos to optics, biology, mathematical theory, and an array of cascading computational and technological developments.

Moyal's own career as an academic had moved on from his appointment as a lecturer at Queen's University, Belfast, in 1946, to a rich period from 1950 in the Department of Mathematics at Manchester University, and brought him to the Australian National University in 1958. Headhunted in 1965 by America's leading national laboratory for the peaceful uses of atomic energy, Argonne National Laboratory, for his work on nuclear physics, probability and stochastic processes, he returned to Australia as a senior professor in the Department of Mathematics at Macquarie University in 1972. A researcher across three fields of mathematics, statistics, and quantum physics, his publications ran to thirty-six major papers but, in the award of a Doctor of Science *honoris causa* by the ANU in 1997, he was pronounced one of the most original thinkers in twentieth-century Australia. Although aware in his retirement of a significant flow-on of his work in quantum mechanics, he did not live to see the final effect of its range and power. Joe Moyal died in May 1998 at the age of 87. He knew, however, that he had fought a singular fight and preserved the correspondence for posterity.[2]

For my part, I had married Joe Moyal in 1963 and, as a historian of Australian science and technology, was alerted after his death to the accelerating impact of his 'Quantum Mechanics as a Statistical Theory' by his former younger colleagues at Macquarie University. I followed its growing presence in the scientific citations at the Web of Science. After five decades, in 2001 they sat at 69 hits (scientists are exultant if they reach the 100 mark), but in 2003 the citations soared to 980, to 1,220 in 2005 and, by 2006 had reached 1,245. In March 2017 citations of the paper at the Web of Science sat at 1,983, and at Google Scholar at 3,129. It was, as Peter Medawar once famously defined the core accomplishment of science, "a seminal theory that had come to stretch far beyond its own creative era and to emerge as a general statement of steadily increasing explanatory power and compass" (Medawar, 1969).

Steered by these colleagues, I would carry the story forward. Alan McIntosh, FAA, who had become head of the Centre for Mathematics and its Applications at the Australian National University, having read a copy of the correspondence, observed, "Joe is putting forward an entirely different formulation of quantum mechanics, a formulation which he is claiming is equivalent to the others and more useful in solving evolution equations, how the system evolves from time to time. Dirac didn't understand it; he didn't think it possible and he contradicts himself. But this is precisely why his [Moyal's] work and his statistical method is being used so widely today" (McIntosh, 2003).

Similarly, Dr John Corbett, emeritus professor of quantum physics at Macquarie, noted that the correspondence revealed "not only how new ideas and approaches are only accepted reluctantly, and how even very good scientists can read their own problems into another's work," but that Dirac was overly concerned with the quantization problem. "While his own method did not give a one-to-one correspondence between a classical quantity and a quantum counterpart," he concluded, "Dirac failed to yield answers

[2] No copy of the original paper survives.

and played his cards close to his chest" (Corbett, 2005).

Delivering the correspondence by email, I sought the further evaluation of several key international scientists working in the field of Moyal phase space whom I traced through the Web of Science. Their response was generous and enlightening. At the Centre of Theoretical Physics in Marseilles, Dr Bruno Iochum, fascinated to find that Moyal of the 'Moyal planes' was "a person," put me in touch with his colleagues, Drs. Joseph Várilly and José Gracia-Bondia, at the University of Costa Rica, San Jose, and the University of Complutense in Madrid respectively, who had conducted their joint research deriving from the Moyal paper. Together they contributed valuable information, checks and insights to my research. "Without dispute," wrote Várilly, "'Quantum mechanics as a statistical theory' is one of the great physical papers of the 20th century" (Várilly, 2003).

In addition, a collegiate duo of American physicists reputed in the field gladly accepted copies of the Dirac-Moyal correspondence and offered their informed judgments. Professor Thomas Curtright of the Department of Physics at the University of Miami summed up: "Seven of the letters are pure gems. They definitely show Dirac to be wrong about some really basic points in quantum mechanics. That by itself is most remarkable. But then they also show that Dirac is basically unfair and incredibly stubborn." "Indeed," he added, "it is stunning to a reader well-versed in quantum mechanics that Dirac — the master formalist — makes such silly mistakes and commits them in writing for posterity" (Curtright, 2003).

Concomitantly, Dr Comas Zachos of the Division of High Energy Physics at Moyal's former stamping ground, Argonne National Laboratory, had published papers featuring Moyal's work and had already recorded that his pioneering paper of 1949 had offered "a grand synthesis of the scattered mathematical machinery into a confident interpretation of quantum mechanics as a statistical theory." Writing to me with substance over several years, he set down: "Moyal's most celebrated pioneering 1949 paper in which he established an independent formulation of quantum mechanics in phase space is well validated by posterity." "This formulation of quantum mechanics serves as describing quantum transport processes in phase space. Such processes are of importance in quantum optics, nuclear and particle physics, condensed matter, the study of semi-classical limits of mesoscopic system and phase transition of classical statistical mechanics. It is the natural language to the study of quantum chaos and decoherence (of utility, e.g., in quantum computing) and provides crucial intuition in quantum mechanical interference problems, probability flows as negative probability backflows and measurements of atomic systems. The mathematical structure of the formulation is of relevance to Lie Algebras, martingales in turbulence, and string theory…In addition, it is significant outside physics, as for example in fundamental work on wavelet methods in signal processing."

I had much to learn. Surprised that Dirac "did not jump at the opportunity to embrace the innovations [that] are now seen to be compatible with this methodology," Zachos also noted that, rather, the great physicist "had declined to give ground even in the final edition of his *Principles of Quantum Mechanics* in 1958" (Zachos, 2005).

This rich polyvocal input into my research — conducted by email with quickening pace — convinced me of the importance of this case study, a study with so high a figure that captured an experience known throughout the world of science. As a historian totally untutored in physics, quantum mechanics and statistics, I profited deeply from the interest of these distinguished scientists and their friendship and zeal. The American scholars subsequently republished 'Quantum Mechanics as a Statistical Theory' in their *Quantum Mechanics in Phase Space. An Overview with Selected Papers* (Zachos, Curtright, Fairlie, 2005).

The manuscript collection, 'P. A. M. Dirac–J. E. Moyal Correspondence 1944–1946', was held by the Basser Library, Australian Academy of Science from 1962 to 2017, when, with the closure of the Library, it was transferred to the Papers of Ann Moyal, National Library of Australia, Canberra. Professor Dirac's letters are written by hand. The J. E. Moyal Medal and Lecture, established in 2000, is awarded annually at Macquarie University in mathematics, statistics and physics.

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The scientific legacy of the Rev. W. B. Clarke

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Abstract

That the collective memory of even so dominant a figure in Australian colonial science as W. B. Clarke has faded 140 years after his death is hardly surprising. What is so striking is the marked variation in the degree to which his legacy is recognised, even where he was arguably the major contributor in his time. He is of continued interest to the Royal Society of NSW, but not so to most other learned societies. Though the focus of much work by Australian historians of science, he is virtually ignored in general histories of the country; remembered in geology, he is almost totally forgotten in meteorology. And when remembered, he has at times been reinterpreted; portrayed as Darwin's colonial 'bulldog', he actually had grave reservations about such theoretical constructs. Clarke's legacy is considered here as Memory Maintained and Restored, Memory Lost, and Myth as Memory.

Key words: Clarke, Australian, Science, History.

Introduction

When William Branwhite Clarke arrived in Sydney in 1839 he already had a considerable cultural and scientific reputation. He had published five books of poetry, had forty-one scientific papers to his name, mostly dealing with meteorology and geology, and had been elected to the prestigious Geological Society of London. Over the next four decades he played a major role in the development of colonial society in the broadest sense of the term. By the year of his death in 1878 he had published over 500 articles ranging from various aspects of science, especially geology, to free trade and the promotion of education (see Michael Organ's *Bibliography of W. B. Clarke*), and had established a worldwide network of scientific correspondence (see Ann Moyal's *The Web of Science*). He had also been very active in the revitalisation of the colony's essentially moribund Philosophical Society in 1866 (under its new name of the Royal Society of New South Wales), the substantial upgrading of the Australian Museum in Sydney, the founding of the University of Sydney and its associated St. Paul's College, the setting up of the Academy of Art (that later became the Art Gallery of New South Wales); and he had served as a Trustee of the Free Public Library. Furthermore, he had been a prolific journalist for Sydney newspapers, especially *The Sydney Morning Herald*, occasionally acting as editor of that journal, and had given strong journalistic support to the expeditions by Leichhardt and Kennedy into remote areas of the continent. His efforts had received international recognition, notably in the awarding to him of the *Murchison Medal* of the Geological Society of London, and by his election to the Royal Society of London, with Charles

Darwin and the eminent economist William Stanley Jevons[1] as sponsors; and locally by the *Clarke Medal* of the Royal Society of New South Wales. All this was achieved in spare time from clerical duties as a priest of the Church of England (see R. W. Young *This Wonderfully Strange Country, Rev. W. B. Clarke Colonial Scientist*).

Clarke was certainly remembered with much respect by scientists who had known him. In the words of his friend, the eminent botanist Rev. Dr. William Woolls, "Mr. Clarke had a remarkable versatility of genius: he was a poet of no mean powers, a liberal theologian, an eloquent classic, an observing naturalist, whilst to the depth of philosophy he added the simplicity of a child and a fund of never failing humour." In the next generation, it was not only geologists such as Richard Daintree and Charles Wilkinson who admired him, but also the highly respected chemist Archibald Liversidge (see Roy Macleod's *Imperial Science under the Southern Cross*). Yet memory fades with time, and less than two decades after his death, Price Warung lamented in *Cosmos Magazine* that the public had so quickly all but forgotten this "Nestor of Australian Philosophers" (a title he attributed to the great botanist von Mueller). Whereas the memory of the general public is notoriously short, Clarke was still remembered well enough in 1887 to be given a substantial entry in the British publication *Dictionary of National Biography* edited by Leslie Stephen. A century later, however, he was dismissed in three condescending sentences over the two volumes of Manning Clark's *A History of Australia*, and was not mentioned in either the *Oxford Companion to Australian History* or Alan Atkinson's recently published *The Europeans in Australia*. Of course, the lengthening of historical experience leads to a thinning out of collective memory, and scholarly specialisation leads to its fragmentation. Nonetheless, with a polymath such as Clarke, who had played an important role in a wide range of scientific, cultural and social aspects of colonial life, fading memory is more problematic.

What then of Clarke almost 140 years further on? To what extent is his legacy maintained in collective memory, and what has been the variable role of historians in its continuation or its loss? I consider these questions especially in the light of comments made by Eugen Rosenstock-Huessy in his controversial, though deeply insightful, *Out of Revolution, Autobiography of Western Man* (1969 pp. 697-8): "the historian is as often the grave-digger of our memories as their restorer. His work tests the duration of living memory, strengthens the rising, and buries the withered," and "Myth, as modern literati use the word, is a substitute for lost memory." The extent to which memory of Clarke has been retained, lost or converted into "myth" varies considerably both between and within the fields of interest in which he worked. As Michael Organ (1998) put it, "A knowledge of the breadth of his output leaves one with the belief that to simply proclaim him 'the Father of Australian geology' is to fail to do justice to his life's work," but dealing with his complete range of interests is beyond the scope of this review, which concentrates on his major scientific work.

[1] During his time at the Sydney Mint in the 1850s, Jevons had first known Clarke when both were members of the Philosophical Society of N.S.W.. — Ed.

Memory Maintained and Restored: Royal Society of New South Wales

The founding and nurturing of the Royal Society was undoubtedly one of Clarke's greatest achievements. As noted above, the Society honours him with the annual award of the Clarke Medal for original research, and he has certainly figured in the publications of the Society, especially in its *Journal & Proceedings*. In *A Contribution to the History of the Royal Society of New South Wales*, that was to have marked the 50th Anniversary of the Society, but which was delayed until 1918 largely owing to the stringencies of war, the prominent botanist J. H. Maiden did much to restore the memory of Clarke's efforts in the founding of the Society and especially in the changing of its name. He reminded his audience that according to Clarke's *Inaugural Addre*ss of 1867 the old Philosophical Society had languished because its previous title gave the impression that the subjects discussed were of an "abstruse and abstract character ... which assigns to it an exclusiveness by which many are deterred from becoming members," and that Clarke had recommended "the more comprehensive and expressive title of the Royal Society" be adopted. Maiden also drew attention to Clarke's recognition of the need for the Society to be multidisciplinary, a stance that it has maintained in the face of the seemingly ever-increasing specialisation of scientific and literary journals.

In the Society's *Centenary Oration, The Challenge to Science, 1866: the Challenge of Science, 1966*, the well-known anthropologist A. P. Elkin praised Clarke as "the 'founding father' of our Royal Society," who, "In true Baconian spirit steered the Society along that path in which it would be able to take up the challenge of the country and the nation *to* science." In the second part of the *Oration*, entitled *The Passing of the Former Challenge*, Elkin proposed that the Society turn its attention to "the philosophical problems raised by science" that "are moral and social on the one hand, and cosmological on the other." Elkin rightly emphasised the importance of such issues in a world of nuclear weapons, and suggested that "the Society pay serious attention to the Philosophy, and by implication to the History of Science." Curiously, however, he made no mention of the assault on contemporary philosophy that was a major part of Clarke's *Inaugural Address* (see below).

In recent decades the *Journal & Proceedings* have included several notable reviews dealing with Clarke's scientific work, such as *The Bibliography of the Rev. W.B. Clarke* by Michael Organ (1994), *...a small fish in a big pond... the Reverend W.B. Clarke (1798-1878): what did he actually do?* by the same author (1998-99), and *Friends, Savants and Founders: W. B. Clarke and J. D. Dana* by Ann Moyal (2012).

Historical books and papers

Important contributions on Clarke were by no means limited to publications by the Royal Society. Indeed, the first really detailed account of Clarke's life and work appeared in 1944 when James Jervis wrote his first-rate review in the *Journal of the Royal Historical Society of Australia*. Clarke's scientific work was later placed in a broader context in Ann Mozley's (1967) *Evolution and the Climate of Opinion in Australia 1840-1876*, and was continued in Moyal's *A Bright and Savage Land* (1986). Popular interest in Clarke was markedly boosted by the details of his personal and family life given in *The Remarkable Reverend Clarke* by Elena Grainger (1986). The appreciation of his scientific effort increased markedly during the next decades with the publishing of Moyal's (2003) *The Web of Science,* a two-volume compilation of Clarke's scientific correspondence (including all of Clarke's letters referred to here), and by R. W. Young in *This Wonderfully Strange Country, Rev. W. B. Clarke Colonial Scientist* (2015). Significant comment on Clarke has also been made in works on other subjects, as for example, in E. M. Webster's *Whirlwinds in the Plain* (1980), where his journalistic support of Ludwig Leichhardt in the confrontation with Sir Thomas Mitchell was reviewed in much detail.

Geology

Given Clarke's pioneering work on the geology of Australia, it is hardly surprising that he is best remembered in that science. For example, in 1911 C. A. Süssmilch said of him, "This great worker, the pioneer geologist of this State, laboured for many years singlehanded in a thinly populated area of vast extent;" and in 1999, when replying to the comment by T. G. Vallance that Clarke had been "a small fish in a small pond," Michael Organ wrote that "Perhaps 'a big fish in a big pond' would be a more appropriate epitaph." But it was not just in volumes recording the history of the development of Australian geology that he is remembered. To the contrary, the naming of the W. B. Clarke Geoscience Centre, at Londonderry, west of Sydney, is clear testimony of his ongoing legacy to Australian geology. That legacy is conveyed by the very site of the Centre on the clays and gravels of Tertiary age that were first described by Clarke in 1842, and by the view westward from it, "where the escarpment of the Blue Mountains forms the side of a great fault, the Wianamatta beds abut against the Hawkesbury rocks or recline at a high angle on the slopes" (Clarke 1867) — reference to the easterly inclination of the Wianamatta beds shows that he recognised the escarpment to be the result of folding rather than just faulting *sensu stricto*. Moreover, the Wianamatta and the Hawkesbury are two of the major stratigraphic units named and mapped by him. The narrow gorges exiting from the Blue Mountains are likewise testimony of that legacy, for it was in a series of articles on these gorges published in *The Sydney Herald* on 12th December 1842 and 3rd January 1843 that Clarke first noted the shortcomings of Charles Darwin's theory of marine erosion of valleys, and tentatively proposed instead that they had been eroded by the streams that flow through them, albeit with once greater discharges. His subsequent mapping of river gravels along the summit and flanks of the escarpment into which the gorges were incised, together with his recognition by 1844 that the fossil fish preserved in the Wianamatta and Hawkesbury sediments were fresh water species, made Darwin's claim of marine erosion of the valleys unlikely (see Young 2007).

An important, although partly forgotten matter, was Clarke's own assessment of the early development of geology, the key to which is probably his *First Lecture on Geology to the Church Book Society* reported in *The Sydney Herald* on 7th April 1843. James Hutton, lauded in most histories as the founder of the discipline, was mentioned only briefly; the real founder in Clarke's eyes was William Smith:

> It was not till the year 1790 that any correct observations appeared to have been made respecting the real state of the surface of the Earth. Mr. William Smith (a man who could never be mentioned without honour as the parent of English Geology), being employed as a surveyor, made the

> observation that the island of England and Scotland was divided into bands of rocks and clays which succeeded each other in a certain order, never reversed, and that the certain distinguishing fossils, found in the rocks and clays, always belonged to the same formation, a discovery which had laid the foundations of the present science. From this dated all that could properly be called Geology.

Smith's forte was systematic mapping, and Clarke was soon to be known as the "Australasian Smith" (see Young 2015).

As important as the Blue Mountains were in Clarke's early work in Australia, the recognition and mapping of major stratigraphic units that figured so prominently in his geological work was initially the product of seven surveys in the Illawarra and Shoalhaven districts on the coast south of Sydney. His first trip southward was early in 1840 with J. D. Dana, who had recently arrived with the U.S. Exploring Expedition; their major findings were summarised on the map of the Illawarra district drawn by Dana in 1840 and, with additions from Clarke, published in 1849. Clarke returned to this district in 1841 with the British geologist J. B. Jukes; their observations, together with those by Clarke elsewhere in the colony, were included in the first geological map of the continent published by Jukes in 1846. During these trips, Clarke had paid specific attention to coal-bearing strata, and by the end of 1847 he had mapped coal over some 17,000 square miles. His mapping was then greatly extended during two major expeditions to the newly discovered goldfields between northern Victoria and southern Queensland in 1851-53. Four decades of geological mapping by him culminated in *The Geological Sketch Map of New South Wales Compiled from the Original map of the Late Rev. W. B. Clarke by Charles Wilkinson Government Geologist*, that was published by the Department of Mines in 1882. Subsequent mapping in the state has essentially been built on the foundation of those pioneering endeavours, and reference to him is scattered throughout numerous geological reports.

Yet this had not been mapping for mapping's sake, but was driven by Clarke's outlining to the Philosophical Society in 1861 of what he saw as "the principal object now in view which is the correlation of our Australasian formations with those of Europe." He has recently been criticised for being "perhaps too wedded to European stratigraphic concepts, tending to 'push' his observations to fit them" (Branagan 2012); perhaps, but how else could Australasian research be integrated into a global stratigraphic system? And behind that endeavour was Clarke's rejection, forcefully stated in his lecture to the Church Book Society in 1843 (reported in *The Herald,* 7 April), of earlier speculation about this land being fundamentally *different*; of being for example, as argued by Blumenbach, part of the sun displaced by a comet, then populated by *different* life forms.

Indeed, it was Clarke's pursuit of the similarities in the geological histories of the continents, especially those of the Southern Hemisphere, that gave rise to perhaps his most important theoretical contribution, that of the sundering of a once vast super-continent. He first speculated on this idea in a letter to his mentor at Cambridge, Adam Sedgwick, after arriving in Australia via southern Africa in 1839. He developed the idea more fully by correspondence with geologists in New Zealand and especially in India, where Ottakar Feistmantel, among others, had begun working in detail on the Gondwana System. Whether Clarke believed in continental drift in its modern sense is uncertain (c.f. Grainger 1982, Moyal 2007, Young 2015), but he certainly was speculating on some form of large-scale continental sundering three-quarters of a century before Alfred Wegener published *Die Entstehung der Kontinente und Ozeane*. Grainger suggested that Clarke "may even have influenced Wegener," but there is no mention of him in *Die Entstehung* — nor, for that matter, in any major reviews of the development of ideas on continental movement.

Colonial life in Australia was transformed by the great gold rushes after 1850, in which Clarke played a very significant, though still disputed, role. Although Edward Hargraves is still widely believed — though not by some experts in the matter — to have been the first discoverer of gold in Australia, both Clarke and Strzelecki claimed to have discovered it at least a decade earlier. The lack of a clear recording of events seems to have been the result not just of the conflicting claims by various "discoverers" (see Young 2015), but also both of government policy and the judgement of later historians. Clarke maintained that when in 1844 he had told Governor Gipps of his discovery of gold several years earlier, the Governor had replied, "Put it away, Mr. Clarke, or we will have our throats cut." Clarke was later accused of fabricating this claim, as for example in *The Rush That Never Ended*, where Geoffrey Blainey wrote "While he has gone down in history as the author of that pithy sentence, 'Put it away etc,' Clarke himself was the author." But, as Clarke had pointed out in *Researches in the Southern Goldfields*, Strzelecki had stated in his *Discovery of Gold in Australia* that Gipps had requested him to remain silent about gold for the same reason that he gave to Clarke.

Memory Lost: Meteorology

The scientific field in which Clarke's important pioneer contributions have been almost completely forgotten is meteorology, even though his output there was second only to that in geology. Before he departed for Australia, Clarke had already published 14 papers on the broad topic of meteorology, especially on the apparent relationships between atmospheric phenomena and volcanic activity, and between vegetation and climate. He then published four more in British journals, mainly from observations recorded on the voyage south. Although useful, these early papers gave little indication of the depth of understanding revealed in 1842 when he published 20 long articles, under the general heading of *Meteorology As Applicable to Australia*, in *The Sydney Herald* (16, 22 January, 7, 12 February, 1, 7, 11 March, 7, 14, 16, 22, 26, 30 April, 6, 16, 24 May, 3, 13, 15, 17 June). These were by no means just summaries of local events, but attempted to explain the major meteorological systems of varying scales operating over and around Australia, and displayed a thorough grasp of relevant knowledge worldwide at that time. These articles essentially formed the foundations of atmospheric studies in Australia.

Of particular importance was his grasp of the dominant role of weather systems moving across the continent from the west, and thereby the need to modify ideas about general circulation in the Southern Hemisphere.

> Now this constant tendency of the wind from the west must materially modify any lower current, should the upper strata

> descend, of which there is no question in many great aerial commotions ... But it is clear that, if westerly winds be constant, the doctrine which gives to the southern hemisphere a complete inverse condition of the direction of the wind must be modified: and then, in some cases, there can be no question, that the law of storms in the southern hemisphere will not appear as a complete reversal of those in the northern.

He also emphasised the importance of varying scales of phenomena, noting that while local winds were essentially a response to thermal and barometric conditions, atmospheric circulation on a much larger scale was dominant in the general movement of weather systems.

The last five of the articles in *The Herald* series dealt with "Hot Winds" and their bearing on the problem of the postulated arid interior. Clarke suggested that aridity might not be the dominant control, but rather that the wind might well be the cause of the desert, as was apparently the case in the deserts that lay between latitudes 15º to 30º N.

> Should this be applicable to the southern hemisphere, then would the interior of Australia, within the course of circuit NW winds be placed within the desert zone of no rain, and the question of the cause of the desert zone might be satisfactorily resolved upon the principles we have adopted.

He was here close to the concept of the dominance of high-pressure systems moving from the west over the arid lands of that latitudinal belt.

Clarke published at least another 35 articles on meteorology between 1843 and 1863. He expanded on Strzelecki's idea of the switch in dominant rotation of winds from left to right in summer, to right to left in winter, thereby laying the foundation of understanding the seasonal change of cells of high and low pressure across the continent. He made valuable additions to Captain Henry Piddington's *The Law of Storms*, especially in noting the great scale of cyclones in the Tasman Sea, that were of real importance in the age of sail. So too was his emphasis on the influx of tropical weather systems into southern Australia. And his highly detailed description in *The Herald* on 28th December 1850 of the great storm at Sydney a week earlier, which drew on observations from six barometers and 10 thermometers, gave weight to his comment in a letter to Adam Sedgwick in 1847, "I have logged about 100 thunderstorms — I put down every wink of lightning, and every grunt of thunder. I am sure that I have made out the law of such storms in the Colony so clear that I could wind one up and set it going."

After about 1845 he became increasingly interested in temporal variations, both short and long term, especially of extreme events such as the cold weather of 1844 that he attributed to the movement of Antarctic icebergs observed as far north as 35º latitude. By 1847 he was propounding changes at the global scale by comparing the fluctuations in temperatures, recorded in the colony and in England, with observations of ice in adjacent oceans: "The cold and wet felt occasionally in New South Wales is probably also due to the ice set free from the Antarctic regions floating northwestwards, just as it flows southwards in the other hemisphere." Then in 1851 he recognised evidence of much greater climatic fluctuations in the remains of former glaciation and frost action near Mt. Kosciuszko, and in the former outlet of Lake

George at Geary's Gap that indicated water levels "96 feet" above the now partly dry lake bed. As most of his observations appeared as articles in *The Sydney Morning Herald*, and as vivid descriptions in his *Researches in the Southern Goldfields*, details of the source and content of them are listed by Moyal (2003) and Young (2015).

The importance of Clarke's contribution in laying the foundations of atmospheric science in Australia was well appreciated by many of his contemporaries and by experts in the succeeding generation. When revising his *Climate of New South Wales* in 1877, the government meteorologist, H. C. Russell, drew substantially on Clarke's observations, and said of him, "In Meteorology, as in all that he did, Mr. Clarke was a most indefatigable worker and painstaking investigator." A decade later in his *Astronomical and Meteorological Workers in New South Wales,* Russell (1888, p 45) again paid tribute to "the very important contributions which came from his busy brain and pen." Clarke's contributions were still recognised after the turn of the century in the short historical review at the beginning of Griffith Taylor's *Australian Meteorology* (1920). But he received no mention among the prominent colonial researchers listed in W. J. Gibbs' *The Origins of Australian Meteorology* (1975) or in the revised edition of that work published by the Bureau of Meteorology in 1998. The only mention of Clarke in the Bureau's *Metarch Pape*rs is in the reprinting of Russell's 1889 paper, and in the *Australian Meteorological Magazine* a deprecating comment about him quoted from a letter by Ludwig Leichhardt that his "head is full of vortices and wind-classification, as you may well suppose from his extraordinary deductions" (Nicholls 2005).

Why Clarke's contributions have been overlooked remains speculative. Gibbs' review certainly extends to contributions made prior to Clarke's arrival in the colony, including those of Philip Parker King, who was Clarke's friend and meteorological correspondent. Perhaps it was Clarke's well-known reputation as a geologist which obscured his meteorological efforts, or it was that their publication mainly in newspapers rather than scientific journals resulted in them being overlooked. But how Russell's work, which was cited by Gibbs, could be read without the tribute to Clarke being noted seems very odd indeed! And the same could be said of a reading of Taylor's book without noting his reference to Clarke. Yet such was the case, and once Clarke was left out of the list of pioneers, the historian essentially had become the "grave digger."

Myth As Memory: Clarke as Darwinist

On page 11 of *The Remarkable Reverend Clarke* Elena Grainger declared that "if T. H. Huxley was Darwin's 'bulldog' in Britain and America, Clarke played the same role in Australia." Is this an accurate statement, or is it really to be seen in the context of a prevailing "myth"? C. S. Lewis in *The Funeral Of A Great Myth*, published in 1967 though written somewhat earlier, argued that "What the Myth uses is a selection from the scientific theories — a selection made at first, and modified afterwards, in obedience to imaginative and emotional needs." The central idea of the mythical vision that Lewis had come to bury (at least philosophically) had its roots early in the 19th Century, and was what its believers called "Development" or "Emergence," and which had attached to itself the scientific hypothesis of "Evolution," especially in the form advanced by Darwin.

Of course, the fossil record of changes in the history of life on earth must be distinguished from the hypotheses advanced to explain that history, and Darwin's major contribution was in the latter category. As the following quotation from *On the Origin of Species* (p 81) regarding the operation of the principle of the survival of the fittest shows, it already had its own metaphysical aura: "we may feel sure that any variation in the least degree injurious would be rigidly destroyed." And the penultimate sentence of that book leaves little doubt about why it was so rapidly incorporated into that prevailing "myth:" "Thus from the war of nature, from famine and death, the most exalted object of which we are capable of conceiving, namely the production of the higher animals, directly follows." That far more than a new scientific theory was being proclaimed is abundantly clear from Thomas Huxley's well-known description of Darwinism as the "New Reformation."

As noted above, while urging the Royal Society to pursue the philosophical setting and impact of science, Elkin in his *Centenary Address* made no mention of Clarke's polemic in the *Inaugural Address* against the then dominant philosophies, which he dismissed by quoting George Lewes' description of them as "a Desert whose only resemblance of vegetation is a mirage." For, Clarke said, "It is one thing to respect the method by which a logical argument is to be maintained, and another to defend the introduction of investigations which are often based on conjecture, and are altogether speculative." He made no attempt to gloss over his Christian commitment, remarking in the *Inaugural Address* that "there appears to me to be only one true Philosophy that which is given to and not elaborated by man," but he was certainly no fundamentalist clinging to the Mosaic account of a six-day creation. To the contrary, in his lecture to the Church Book Society in 1843, he attacked the so-called "Scriptural Geologists" who held such views, and in reference to claims in Cowper's *The Task*, he stated that "if the date of the Earth, called 'in the beginning' was revealed to Moses, he had never been able to find where Moses said so; it was a pity that if Cowper knew the date he had not told us, and saved all the controversy." Moreover, he was the leading colonial palaeontologist and knew better than anyone else in Australia the great changes in the form of life that had occurred on this continent: as Richard Owen commented in a letter to him in 1872, "*Timeo Clarkeum et fossilia mittenem*" (I fear Clarke and the fossils he sends).

Although Clarke was also on generally cordial terms with Darwin, who eventually was one of his sponsors for his election to the Royal Society of London, care must be taken against reading too much into these relationships. Grainger entitled the chapter in which she discussed *The Origin of Species* as "Mr. Darwin's Book," but as is clear from a letter to Adam Sedgwick in 1839, the book to which Clarke actually referred by this title was not *The Origin of Species*, but rather Darwin's *Voyage of H.M.S. Beagle*. Indeed, in *The Geology of Australia*, a lecture given to the Philosophical Society of New South Wales in 1861, the year in which he first read *The Origin of Species*, Clarke's only reference to it was dismissive. Much also has been made of a passage in the *Inaugural Address* of 1867: "Nor is there any objection to the statement of arguments relating to the Origin of Species, or observations on which these arguments are based." But as Darwin is not mentioned by name, nor Origin of

Species set in the same format as all other references in the *Address*, Clarke was presumably commenting on the general hypothesis rather than the specific book. His rejection of Darwin's hypothesis was shown beyond doubt in *Extinct Animals* published in *The Sydney Herald* on 31st May 1869 where he wrote that he could not accept that "recent animals are the *offspring of the olden forms*; I believe that species as such were made by the Creator." This was not a clinging to fundamentalism in response to any Darwinian challenge, for the operative words were *species as such*. Clarke was well aware of variations within species, of the numerous examples of the sterility of cross breeding between species, and of the problematic nature of the extinction of species in the context of both space and time. It expresses rather his belief in structure and purpose, not chance, as the basic determinant of the history of life on Earth. That belief owed as much to his classical Aristotelian training, with its emphasis on change being limited to the *attributes* of species (*substances*) rather than to species *per se*, as it did to his Christian theology.

Furthermore, given Clarke's well-known deep concern for social welfare, especially that of convicts and Aborigines, his estrangement from Darwinism was surely completed by the rise of Social Darwinism that applied the rule of survival of the fittest to human affairs, and which was perhaps most aptly expressed in Darwin's own words from the *Descent of Man*:

> … we institute poor-laws, and our medical men exert their utmost skill to save the life of every one to the last moment … Thus the weak members of civilised societies propagate their kind. No one who has attended to the breeding of domestic animals will doubt that this must be highly injurious to the race of man. It is surprising how soon a want of care, or care wrongly corrected leads to the degeneration of a domestic race; but excepting in the case of man itself, hardly any one is so ignorant to allow his worst animals to breed.

Ultimately Clarke's unwaveringly orthodox Christian faith could not be reconciled with, as he put it in a letter to John Dunmore Lang in 1877, "those who derive 'Man' from a speck of abbuminous [albuminous] matter in a dirty ditch." To call him "Darwin's bulldog" was substituting myth for memory!

Research into comparative anatomy and molecular biology since Clarke's time has put paid to his claim that species are independent of their predecessors, but the Darwinian concept of life progressing from very limited beginnings to an increasingly complex array of forms has been subject to doubt in recent decades. As Simon Conway-Morris wrote in the *Crucible of Creation*, "… although the Darwinian framework provides the logical underpinning to explain organic evolution, the actual pattern of life we observe may require a more complex set of explanations." Thus, Clarke's misgivings about the Darwinian band-wagon, especially of the triumphalism trumpeted by Huxley, now seem more to the point than they did several decades ago.

Conclusion

Memory, whether personal or collective, obviously may range from true recollection to apparently total loss, while what may seem to be true can be actually a reconstruction to fit prevailing ideas or sentiments. Clarke's role as a founding father does much to account for the continuing and prominent memory of him in the Royal Society of New South Wales and in Australian geology in general. Yet in both cases there is a prevailing tendency to look to the past as well as the present; geology is by its very nature an historical science, and is conscious of the major shifts that have occurred in its own development, while in deliberately maintaining a broad range of interests the Royal Society has essentially avoided the tight focussing on the latest discoveries characteristic of many specialist societies. Of course, pitfalls are ever present, as for example the dressing up of Clarke in Darwinian clothing. Australian historians of science have shown the importance of Clarke to our understanding of colonial society, and he remains relevant today especially because the theme of "Advancing Australia" underlay so much of his work, and, as he warned in *The Sydney Morning Herald* on 1st January 1847, "... we see in the present indefatigable exertions to develope [*sic*] the capabilities of New Holland something more than the solution of hydrographical or geographical problems."

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Understanding and countering climate science denial

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Abstract

Science denial causes a range of damaging impacts on society. This is particularly the case with climate science denial, which has resulted in strong polarization around a non-controversial scientific issue, and prolific dissemination of climate misinformation. This in turn has had the effect of reducing public acceptance of climate change, and eroding support for policies to mitigate climate change. In order to develop effective responses to science denial, it is necessary to first understand the drivers of science denial, which leads to deeper understanding of the techniques employed to cast doubt on the reality of climate change. Analysis of denialist techniques can inform development of interventions that neutralize misinformation. Inoculation has been shown to be an effective way to preemptively reduce the influence of climate science denial. Two methods to practically implement inoculation are misconception-based learning (teaching science by addressing scientific misconceptions) and techno-cognition (an interdisciplinary approach that implements psychological principles in the design of technological solutions to misinformation). Interventions and procedures developed for the countering of climate misinformation may also be applied to other scientific topics rife with misinformation, such as vaccination and evolution.

Introduction

There is an overwhelming scientific consensus that humans are causing global warming. Between 90 to 100% of climate scientists have concluded that humans are causing global warming, with a number of studies converging on 97% consensus (Cook et al., 2016). Despite the strengthening consensus, a small proportion of the U.S. public continue to reject the findings of mainstream climate science (Leiserowitz et al., 2017). This small but vocal minority has persistently and prolifically produced misinformation about climate change, with the purpose of confusing the public about the reality of human-caused climate change.

Misinformation is commonly defined as information that is initially presented as true but later shown to be false (Lewandowsky et al. 2012). There is growing awareness of the damaging and significant impacts of misinformation. In 2014, the World Economic Forum named online misinformation as one of the top ten trends of global concern (WEF, 2014). In recognition of the salience of misinformation, Oxford Dictionary named "post-truth" the 2016 word of the year (Flood, 2016). One year later, Collins Dictionary named "fake news" the 2017 word of the year (Flood, 2017).

Climate misinformation has contributed to public misperceptions about climate change (McCright and Dunlap, 2010). For example, there is a significant gap between scientific understanding of climate change, and public perceptions, with only 12% of the American public aware that the scientific consensus on climate change is greater than 90% (Leiserowitz et al. 2017). Students hold a number of misconceptions about the greenhouse effect and its role in causing global warming (Chang and Pascua, 2015). These misconceptions are dangerous because they reduce concern about climate change and support for mitigation policies (van der Linden, 2017; Ranney and Clark, 2017).

Understanding science denial

Science denial is the unwillingness to accept existing scientific evidence. In the case of climate science denial, this may apply to evidence supporting the existence of climate change, humanity's role in causing recent global warming, and/or the severity of climate impacts. A number of terms have been used to characterize climate science denial, such as scepticism, contrarianism, dismissal, dissent, doubt, or anti-climate change. Most common is the term *sceptic* (e.g., Capstick and Pidgeon, 2013; Rahmstorf, 2004). However, using the term sceptic to describe the rejection of scientific evidence is problematic and misleading (Lewandowsky et al., 2016; Odenbaugh, 2016). Genuine scientific scepticism requires an evidence-based approach, eschewing pseudo-scientific principles. This is the polar opposite to science denial, which involves denial of inconvenient evidence and eager adoption of pseudo-scientific arguments if they support preconceptions. Consequently, this paper refers to the rejection of mainstream climate science as *climate science denial*. We begin our examination by first exploring what motivates some people to reject climate science.

Psychological drivers of science denial

A survey-of-surveys found that the strongest drivers of climate beliefs are political affiliation and political ideology (Hornsey et al. 2016). Politics is a greater influence on climate perceptions than education, income level, gender, race, and even science literacy levels. Why would political beliefs influence a person's views on a scientific matter such as climate change? The answer is aversion to proposed policies to mitigate human-caused global warming. When political conservatives are presented with information about climate change as well as one of two proposed solutions to climate change (either regulation of pollution or nuclear energy), they respond positively to the nuclear version but negatively to the regulation version (Campbell and Kay, 2014). Disliking the solution to climate change, political conservatives are predisposed to deny that there's a problem that needs solving.

While individual cognition plays a strong role in people's climate attitudes, social and external cues are also important. One of the strongest external influences are cues from political elites (Brulle et al., 2012). Public concern about climate change dropped dramatically around 2009. Analysis of public surveys conducted over this time found that the change in climate attitudes was due primarily to elite cues (Mildenberger and Leiserowitz, 2017). Over this same time period, there was a sharp up-tick in the production of misinformation targeting climate science (Boussalis and Coan, 2016; see Figure 2). Putting these disparate studies together, we see that misinformation disseminated by conservative leaders played a strong part in reducing public concern about climate change.

Figure 1, derived from Cook and Lewandowsky (2016), provides a concise visual summary of some of the contributing factors to misconceptions about climate change. The graph shows survey results of perceived consensus, with the horizontal axis representing political ideology, depicting clearly the gap between public perceptions of consensus and the actual 97% agreement among climate scientists that humans are causing global warming.

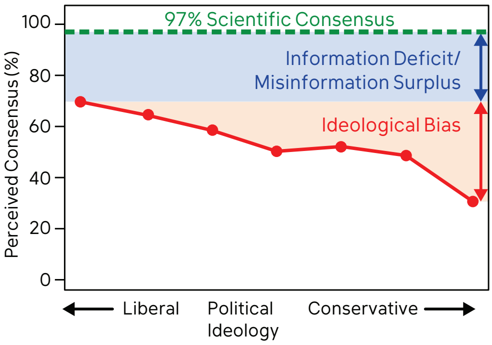

Figure 1: The consensus gap (Cook and Lewandowsky, 2016).

While political ideology has a strong influence on climate perceptions, there is still a large "consensus gap" among political liberals who possess no ideological reason to reject climate science. This "liberal consensus gap" is driven by either lack of awareness of the consensus, or misinformation that casts doubt on the consensus. Climate misperceptions are the result of both cultural biases and informational deficiencies.

The origin of climate science denial

Climate change hasn't always been a polarized, partisan issue. In 1989, Republican President George H. W. Bush promised to "fight the greenhouse effect with the White House effect" (Peterson, 1989, p. A1). However, the issue gradually became polarized due to misinformation campaigns in the early 1990s conducted by conservative think-tanks with the purpose of undermining the Kyoto Protocol (McCright and Dunlap, 2000). These campaigns were enabled and amplified by billions of dollars of funding from the fossil fuel industry (Brulle, 2014; Farrell, 2016a; Farrell, 2016b). Initially, conservative think-tanks disseminated their misinformation through the publication of a number of books sceptical about environmental science and policy (Jacques et al., 2008).

To disseminate their messages, think-tanks relied on a small number of contrarian scientists. Only a small minority of climate scientists reject human-caused global warming (Anderegg et al., 2010; Doran and Zimmerman, 2009), and climate misinformation has a vanishingly small presence in the scientific literature (Cook et al., 2013; Oreskes, 2004). The few number of papers that do manage to get published in peer-reviewed journals have been shown to possess fatal flaws in their analysis (Abraham et al., 2014; Benestad et al., 2016). However, conservative think-tanks have exploited the journalistic norm of media balance to ensure that contrarian voices receive roughly equivalent media coverage to mainstream climate scientists (Painter and Ashe, 2012). The prevalence of false balance coverage in mainstream media has had broad impact, with analysis indicating semantic similarities between misinformation, media coverage, and U.S. Presidential statements (Farrell, 2016b). The spilling of misinformation into public statements by political leaders is especially significant given that cues from political elites has been found to be a crucially important influence on public concern over climate change.

Rejection of climate science continues unabated. An analysis of conservative think-tank articles about climate change found that misinformation casting doubt on climate science has been on the increase relative to arguments against climate policy, as depicted in Figure 2 (Boussalis and Coan, 2016). In 2016, the most shared climate story on social media featured the Global Warming

Petition Project: an online petition listing tens of thousands of dissenting people with a science degree as evidence that there was no scientific consensus on climate change (Readfearn, 2016).

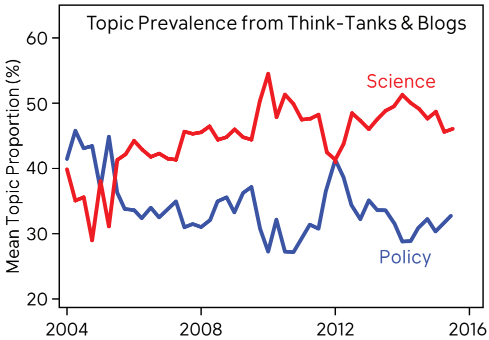

Figure 2: Relative increase of climate science denial relative to climate policy denial (Boussalis & Coan, 2016, with updated data incorporating blog posts).

Impacts of misinformation

Climate misinformation causes a number of negative impacts. First, it can lower public perceptions of climate change. Ranney and Clark (2016) found that exposing people to just a few misleading statistics lowered acceptance of climate change as well as confidence in their understanding of the science. Similarly, showing a single piece of misinformation about the scientific consensus on climate change significantly decreases perceived consensus (Cook et al., 2017; van der Linden et al., 2017). These manufactured misconceptions have consequential flow-on effects. Understanding of the greenhouse mechanism and perceived consensus both have a strong influence on acceptance of the reality of human-caused global warming, and support for mitigation policies (Ranney and Clark, 2016; van der Linden, 2015).

Second, misinformation can cancel out the positive effect of accurate information. McCright et al. (2017) found that denialist frames reduced the positive effect of a number of different climate frames. Van der Linden et al. (2017) found that when participants were presented with information about the scientific consensus alongside misinformation casting doubt on the consensus, the overall effect was no significant change in perceived consensus. Cook et al. (2017) found that false balance media coverage of climate change, where factual information was presented along with misinformation, resulted in a decreased in perceived consensus.

Third, misinformation has a polarizing effect, disproportionately influencing political conservatives (Cook et al., 2017; van der Linden et al., 2017). Consequently, communities that receive misinformation show a divergence in climate attitudes along political lines.

Lastly, another mostly overlooked but dangerous effect of climate denial is the misconception of pluralistic ignorance—the lack of awareness among people concerned about climate change that most people share their concern. National surveys of the U.S. public find that most of the public are alarmed or concerned about climate change (Leiserowitz et al., 2017), but also that they think they are in the minority. This causes people to self-censor and refrain from discussing climate change with their friends (Geiger and Swim, 2016). This silence in turn reinforces the misconception of pluralistic ignorance, resulting in a "spiral of silence" (Maibach et al., 2016). Pluralistic ignorance and the subsequent climate silence is another insidious impact of a small but vocal dissenting minority.

The techniques of science denial

Content analysis of conservative think-tank articles about climate change has identified three major topics in denialist text: science, policy, and scientific integrity (Boussalis and Coan, 2016). Within the science topic, Rahmstorf (2004) lists three categories of misinformation: trend (global warming isn't happening), attribution (humans aren't causing it), and impact (climate impacts are not bad). Poortinga et al. (2011) found that denial of one aspect of climate science (e.g., trend) was associated with denial of other aspects of climate science (e.g., impact).

However, there is little coherence across these positions—a denialist blog can be seen arguing that global warming isn't happening one day, then claiming that global warming is caused by the sun the next day (Lewandowsky et al., 2016). The one consistent theme among denialist claims is the conclusion of each argument—opposition to climate mitigation policies. Climate science denial is not a coherent, evidence-based worldview—rather, it is a collection of rhetorical arguments pursuing political objectives.

Among the various movements that reject a scientific consensus, whether it be on climate change, evolutionary biology, or the health impacts of smoking, five characteristics or techniques of science denial are observed (Diethelm and McKee, 2009; Hoofnagle, 2007).

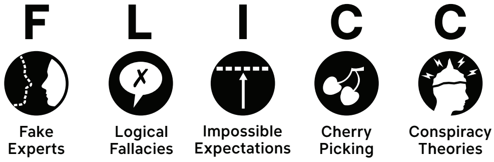

Figure 3: FLICC—the five characteristics of science denial (Cook et al., 2015; Hoofnagle, 2007).

Fake experts: This involves spokespeople who convey the impression of expertise on a topic and yet possess little relevant expertise. The Global Warming Petition Project is the most prevalent form of this technique within climate misinformation, featuring 31,000 signatories of an online petition dissenting against human-caused global warming. However, 99.9% of the signatories, while holding a science degree, possess no expertise in climate science. This petition has been found experimentally to be one of the most effective denialist arguments in lowering acceptance of climate change (van der Linden et al., 2017).

Logical fallacies: Arguments designed to persuade people consist of one or more premises, leading to a conclusion. Climate denialist arguments typically contain fatal logical flaws (Cook et al., in review). There are three classes of logical fallacies found in climate misinformation: fallacies of relevance (where the premises are irrelevant to the conclusion), scope (where not all relevant evidence is considered), and presumption (where the argument contains false premises).

Impossible expectations: This involves demanding unrealistic levels of proof, or misrepresenting the nature of scientific uncertainty. As science is typically probabilistic, calls for absolute scientific certainty are an effective method of casting doubt on scientific findings. This denialist technique is known as "Scientific Certainty Argumentation Methods" (SCAMS, Freudenberg et al., 2008).

Cherry picking: This technique is defined as "selectively chooses data leading to a desired conclusion that differs from the conclusion arising from all the available data" (Cook et al, in review). A common example of cherry picking is arguing that global warming isn't happening because of cold weather in a particular location at the same time that the planet as a whole is experiencing record high temperatures.

Conspiracy theories: Around 20% of the U.S. public believe that climate change is a scientific hoax (Lewandowsky et al., 2013). Conspiracy theories have a number of negative effects, even when people are not convinced by them. They can lower support for climate action (van der Linden, 2015), decrease one's intent to reduce one's carbon footprint (Jolley and Douglas, 2014), and decrease trust in government (Einstein and Glick, 2014).

It is important to recognise that denialist techniques may manifest from both genuine belief and intentional deception, and that it is virtually impossible to distinguish between the two. This is because ideologically-driven denial causes psychological biases that manifest in the same type of denialist behaviour as intentional deception. For example, people ascribe greater expertise to spokespeople whom they agree with, resulting in the vulnerability of relying on fake experts (Kahan, 2011). Correia (2011) argues that motivational biases can cause people to use a number of logical fallacies in false arguments, which also explains why these types of arguments tend to be so persuasive. Impossible expectations can arise from disconfirmation bias—where threatening evidence is vigorously opposed. The flip side of disconfirmation bias is confirmation bias—where people place greater weight on evidence that supports their prior beliefs—resulting in cherry picking. Lastly, climate science denial has been associated with conspiratorial thinking (Lewandowsky et al., 2013).

Responding to science denial

As the use of denialist techniques may arise from genuine belief, accusing people who adopt these techniques of intentional deception is problematic (and often incorrect). A more robust response is to focus on the techniques employed, rather than the often-unknowable intentions of the misinformer. Diethelm and McKee (2009) argue that identifying and exposing denialist tactics are necessary in order to counter science denial. Critical thinking analysis of climate myths is useful in developing refutations (Cook et al., in review).

Debunking

Once misinformation has taken hold, it is extremely difficult to dislodge (for a review of research into debunking misinformation, see Lewandowsky et al. 2012; Swire and Ecker, in press). If a refutation threatens a person's worldview, it can even cause a counterproductive backfire effect (Hart and Nisbet, 2012). Informing people that a piece of information is false creates a gap in their mental model of the world. If the gap is not filled by a replacement fact, the myth will continue to influence people (Seifert, 2002). Consequently, refutations are most effective when they include a factual replacement that meets the causal explanations supplied by the original misinformation (Ecker et al., 2015). Another element of an effective debunking is a warning preceding the myth, which makes people cognitively alert and less likely to be influenced by the misinformation (Ecker et al., 2010).

Inoculation

Research indicates that wherever possible when countering misinformation, prevention is better than cure (Bolsen and Druckman, 2015). Inoculation theory offers one framework for pre-emptive strategies to neutralize misinformation. This approach applies the concept of vaccination to knowledge (McGuire and Papageorgis, 1961). Just as exposure to a weak form of a virus helps people build resistance to the actual virus, similarly when people are exposed to a weak form of misinformation, they become less vulnerable to being influenced by actual misinformation. An inoculating text requires two elements: a warning of the threat of being misinformed, and counterarguments explaining how the misinformation is false.

The efficacy of inoculation against misinformation has been found in several studies involving climate misinformation. One experiment found that after specific flaws in the Global Warming Petition Project were explained to participants, the misinformation was mostly neutralized (van der Linden et al., 2017). In another experiment, when participants received an explanation of how false balance media coverage can mislead people, the typical negative impact of false balance media coverage was removed (Cook et al., 2017). This study also found that explaining a general technique of misinformation was effective in neutralizing the misinformation without actually mentioning the specific myth. Figure 4 shows how climate misinformation has a disproportionate effect among political conservatives (orange line) but is completely neutralized across the political spectrum after receiving an inoculation treatment (blue line).

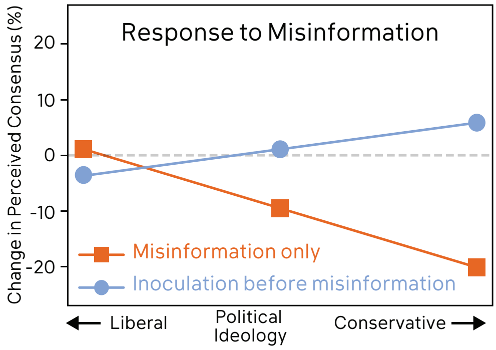

Figure 4: Inoculation (Cook et al. 2017).

This approach of general inoculation without mentioning a specific myth is consistent with the idea of an "umbrella of protection", with inoculation found to convey resistance to other arguments besides the one mentioned in the inoculation (Parker et al., 2012; Pfau et al., 1997). It also echoes a millennia-old approach advocated by Aristotle, who argued that understanding the logical fallacies of false arguments provides a universal safeguard against misinformation (Compton, 2005). This is particularly relevant with climate science denialist arguments, which employ recurrent fallacious errors (Cook et al., in review).

Another benefit of inoculation is that people exposed to an inoculation are more likely to talk about the issue (Ivanov et al., 2015). This is particularly relevant given the prevalent "climate silence", with even people who are alarmed or concerned about climate change mostly not talking about climate change with family and friends (Maibach et al., 2016). One of the drivers of this climate silence is fear of looking incompetent (Geiger and Swim, 2016). Consequently, it is possible that inoculating people against counter-arguments from denialists mitigate this fear.

Misconception-based learning

Misconception-based learning offers a powerful and practical way to apply inoculation in an educational setting. This involves teaching scientific concepts by examining misconceptions and how they distort the science, or by critiquing misinformation and the techniques employed to mislead. Misconception-based learning has been found to be one of the most powerful ways of teaching science, with a number of benefits in comparison to standard science teaching that fails to address misconceptions. It leads to greater and longer lasting learning gains (McCuin et al., 2014), improved argumentative and critical thinking skills (Kuhn and Crowell, 2011; Berland and Reiser, 2008; Todd and O'Brien, 2016), and is more engaging to students (Mason et al., 2008).

Consequently, teachers are recommended to benefit from courses that target climate misconceptions (Frankie, 2014). Educators have already employed this teaching approach in classrooms (Bedford, 2010; Cook et al., 2014; Lambert and Bleicher, 2017; Lovitt and Shuyler, 2016). There have also been attempts to develop educational resources for educators, in the form of a textbook (Bedford and Cook, 2016) and a Massive Open Online Course (Cook et al. 2015). Nevertheless, there remains a dearth of educational resources that adopt a misconception-based learning approach (Tippett, 2010), and further development of resources using this approach is required.

Technocognition

While psychological research offers best practices for designing refutation content in response to misinformation, there is also a need to develop ways to deploy such content in a timely and scaleable fashion. Given that social media and the Internet have contributed to the dissemination and amplification of misinformation, it is fitting (and indeed necessary) that technology should be employed to neutralize misinformation's influence. However, technological solutions can be ineffective or counterproductive. Zollo et al. (2017) found that Facebook fact-checks caused conspiratorial users to increase their engagement with conspiratorial posts. General warnings about fake-news run the danger of breeding cynicism about news articles in general (Pennycook and Rand, 2017; van Duyn and Collier, 2017).

In order for technological solutions to be most effective, they should incorporate the findings of psychological research, an approach known as "technocognition" (Lewandowsky et al., 2017). This is an interdisciplinary approach that combines research findings from psychology, critical thinking approaches from philosophy, and behavioural economics principles, in the design of information architectures deployed via scaleable, technological solutions.

For example, automatic detection and instant assessment of the veracity of articles is considered the "holy grail" of fact-checking (Hassan et al., 2015). There are a number of ways that researchers are exploring the detection of misinformation, with the approaches grouped into linguistic or networking approaches (Conroy et al., 2015). Linguistic approaches include analysing language structure, discourse analysis, and using machine learning to sort text into categories. Network approaches include social network analysis and construction of knowledge networks in order to assess how new claims integrate within existing knowledge structures.

While automatic detection of misinformation is a steep challenge, the characteristics of climate science denial mean that real-time debunking is a practical reality. The denialist arguments deployed today are the same arguments deployed in the early 1990s (McCright and Dunlap, 2000). The static nature of climate misinformation means that the last few decades offer a vast corpus of data containing consistent textual patterns, potentially allowing the detection of specific denialist claims. Automated analysis of climate misinformation is already being conducted, with Boussalis and Coan (2016) analysing conservative think-tank articles using a supervised machine-learning technique. This enabled them to detect overarching topic categories such as science, policy, and scientific integrity. This research needs to be extended to be able to detect specific denialist claims about climate change, which could then be mapped to refutations in real-world, automated applications.

Conclusion

Fake news and post-truthism has become a highly salient issue in recent times, with misinformation playing prominent roles in the Brexit and U.S. Presidential elections. While the mainstreaming of post-truthism is a recent phenomenon, climate misinformation has existed for decades and there is a corresponding large body of research studying its nature and how to counter it.

This research tells us that the damaging influence of misinformation cannot be ignored. Fortunately, there is a large and growing body of psychological research into understanding and responding to climate misinformation. These lessons need to be implemented in technological solutions that seek to neutralize the influence of misinformation in broad, scalable applications.

The lessons learnt from the study of climate misinformation can also be applied to other disciplines. Misinformation abounds in other scientific topics such as vaccination, health, and evolution. Consequently, the procedures and applications being developed to counter climate misinformation may also be adapted and applied to science denial in general.

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A guide to the evolution and classification of Australian birds in 2017

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Abstract

This article was first published in 'The Australian Bird Guide' (CSIRO Publishing, 2017). It is reproduced here with minor updates and modifications. Scientific names of individual species are listed in an Appendix except where pertinent to points in the main text.

The recently published *Australian Bird Guide* (Menkhorst et al., 2017) comes at a time of tremendous and ongoing change in our understanding of bird evolution and how the classifications we adopt can best summarize that understanding.

Imagine two Australian ornithologists, one from 1935 and one from 1975, finding themselves perusing the new field guide in 2017 when this is being written. Both recognize most but not all of the birds in it. Neither recognizes the Eungella Honeyeater (but that 1962 photograph in *Emu* of a supposed Bridled Honeyeater now makes more sense to our 1975 friend). The Grey Grasswren, officially described in 1968 and thus unknown to our 1935 colleague, was found in 1975 in South Australia beyond where it was first discovered around the western parts of the New South Wales-Queensland border. Western Whipbirds, thought in 1935 to be heading to extinction in Western Australia, had been confirmed in eastern Australia just two years earlier in 1933.

Both our ornithologists can see how bird names have changed and find much to talk about in this book, but it's the ways in which we now understand groups of birds to be related to each other that really animates their conversation. Chats are honeyeaters. "Well, yes, I suppose that's nearly been suggested," the 1975 worker says. Owlet-nightjars next to swifts. "Surely, you modern people have been misled!" Falcons next to parrots and not with other diurnal birds of prey. "Now you're delirious!" Budgerigars close relatives of lorikeets, the Scrub-tits of whitefaces? "Madness!" Shrewder, well-informed ornithologists of any era would wryly note that hints of these relationships were often seen in behaviour, eggs, nests, anatomy, moults and plumage.

The point here is that a revolution in ornithology, especially in systematics (the scientific study of relationships and how to classify according to those relationships), began in the late 1960s and today shows little sign of stopping because of the production of new field guides, such as the 2017 *Bird Guide*. Arguably, American ornithologist Charles Sibley started it by studying bird systematics through molecules, first proteins then DNA, and especially at the higher taxonomic levels of order and family. Since the 1980s, techniques to read and analyse DNA sequences have improved such that we can now sample DNA from most of the genome – the full complement of DNA in a cell. DNA provides new frameworks with which to understand how species are related to each other in the avian evolutionary tree of life, or phylogeny. A well-supported phylogeny helps us assess how any aspect of bird biology has changed during the various processes of evolution.

Charles Sibley placed the birds of Australia front and centre in this global, ornithological revolution, along with those of New Guinea and New Zealand (Sibley and Ahlquist, 1985). In looking at why this happened, I hope the reader of today, if not our imaginary 1935 and 1975 friends as well, will embrace three ideas. First, science constantly refines our understanding of the avian phylogenetic tree and how we use classification from the Class 'Aves', right down to the level of the species, to summarize that understanding. There are mis-steps along the way, for sure, but that is how science, and people, work. Second, the 2017 *Guide* and its successors *should* look very different from each other and from their predecessors in the species and groups they recognize. Third, research in systematics can enliven the way one observes any bird. When observing a bird, we are looking at the latest steps in ongoing and open-ended evolution. That makes things far more interesting than if our understanding of the birds and the names we use all just stood still.

The Big Picture

Observing a community of birds is also akin to looking at different branches of the phylogenetic tree of birds. A brief summary of our current understanding of the avian tree of life from the roots to the tips will be helpful (see details in Jarvis et al., 2014; Prum et al., 2015).

At the tree's trunk, living birds divide into Palæognathæ (ratites, tinamous) and Neognathæ (all others). The palæognaths continue to surprise. The flighted tinamous of the Americas are more closely related to the extinct New Zealand moas among the flightless ratites (emus, cassowaries and so on) than some of the latter are to each other. Kiwis appear closer to the extinct elephant birds of Madagascar (Mitchell et al., 2014). A corollary is that flight must have been lost multiple times in the evolution of palæognathous birds.

The Neognathæ, in turn, branches into the Galloanseres (waterfowls and chicken-like birds) and the Neoaves (all other birds). Research in the study of whole genomes in 2015 challenged the view suggested by similar research from 2014. It is fair to say that much of this debate centres on how, in the absence of a complete fossil record, our genomic technologies can recover from DNA any kind of signal of evolutionary events that happened a very long time ago. It is also fair to remind ourselves that while it is always tempting to think of a new study of avian relationships as being the best or final word on a topic to date (and maybe it is), the next study will likely differ (and it did — see Burleigh et al. 2015!), however slightly, but, again, that is how science works. So, while it is reassuring that the composition of most of the major groups of birds seems to be settled, there is still uncertainty as to where some of them fit on the avian evolutionary tree relative to each other. For example, it is now not debated that swifts, nightjars, owlet-nightjars, frogmouths and hummingbirds form a natural evolutionary grouping. Research published at the end of 2014 suggested that that group is embedded in the Neoaves whereas Prum et al., (2015) placed it as the closest living relative of all other Neoaves. Other differences are apparent among the two recent genomic studies but I am struck by the commonalities more than the differences. For example, Jarvis et al. (2014) recognized that most Neoaves are in what they called the Passerea, which has several main lineages, the two main ones being so-called "core" landbirds (Telluraves) and waterbirds (Aequornithia). The Telluraves branches into Australaves (passerines, parrots, falcons, South American seriemas) and Afroaves (kingfishers and relatives, owls, eagles, woodpeckers, hornbills, trogons). Prum et al. (2015) retained the composition and structure of the Telluraves, for example, especially its two enormous component groups together in the same pattern of relationships but differs from the earlier work in how the ever-mysterious South American Hoatzin is related to them. I can live with that kind of debate! Resolution of these debates will depend on how well we can analyse any signal of the deep evolutionary past of birds that is present in their genomes.

A closer look

Considering some neognathous birds can deepen one's appreciation of Australia's role in bird evolution. Megapodes (mound-builders, such as the familiar Australian Brush-turkey), Plains-wanderer and Magpie Goose each have their closest living phylogenetic connections in South America, the first being most closely related to curassows and guans, the second closest to seedsnipe, and the third to the marvellously named screamers. Indeed, the Magpie Goose when so considered is a very special anseriform bird (ducks, geese, swans). It sits on its own branch in the anseriform phylogenetic tree, South America's three species of screamers being on another and then all other living anseriforms essentially making up a third and final "very bushy" branch. Next, Australia's four smallest rails, the White-browed, Spotted, Spotless and Baillon's Crakes, far from being a cohesive evolutionary group, apparently represent three different lineages (Garcia-R. et al., 2014). The White-browed appears to be most closely related to a similarly odd African bird, the Striped Crake, and the bush-hens. The Spotted is closest to a handful of similar *Porzana* species worldwide, whereas Spotless and Baillon's are on a different branch as their own closest relatives. This is why they have recently been assigned to a different genus, *Zapornia*, which is not very closely related to *Porzana*. It also reminds us that a "body plan" like that of small crakes may not always be a good indicator of who is most closely related to whom.

Parrots and passerines (the latter loosely termed 'perching birds'), which turn out to be each other's closest relatives in a phylogenetically surprising result, yielded still further phylogenetic surprises. In passerine evolution, the first branching point led to New Zealand wrens in one lineage and all other passerines in the other. Similarly in parrots, the first branching point led to New Zealand's kakapo, kea and kakas in one lineage and to all other parrots in the other. Our understanding of passerine evolution has advanced steadily to the point where remembering the detail of what we have learned is a formidable task. In essence, the lineage in passerines that led to all species other than New Zealand wrens subdivided into suboscines (represented on mainland Australia only by pittas), and oscines or songbirds. The deepest lineages of the oscines are in Australia and New Guinea (Australo-Papua),

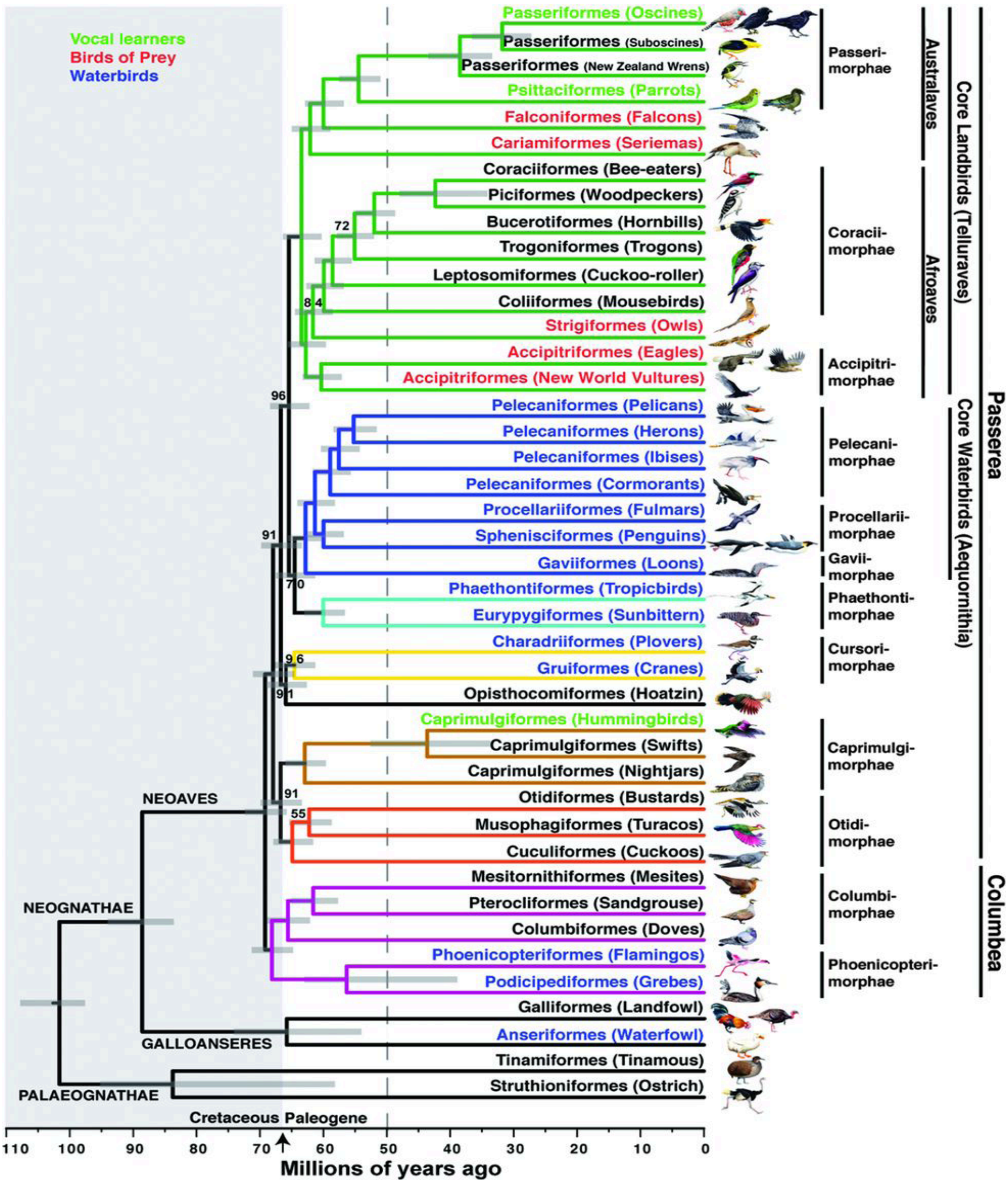

Figure 1: This figure is reproduced from a paper published in *Science* in 2014 (Jarvis et al. 2014). It is a summary or hypothesis of the relationships among the major groups of the world's birds based on an extensive dataset of avian genomes. While not the final word in pattern of relationships, the different colours used for the names of different groups indicate various aspects of avian biology and how many times they may have evolved independently. Light green names, for example, applied to oscine passerines, parrots and hummingbirds show that the biological mechanisms for learning of vocalizations have evolved independently at least twice, and red names show that predation has evolved twice.

this being our current understanding of a finding Sibley first reported in 1985 (Sibley and Ahlquist, 1985). Examples include so many birds characteristic of Australia (and New Guinea) that have no very close relatives in the Northern Hemisphere despite some having similar sounding English names: lyrebirds, scrub-birds, bowerbirds, treecreepers, whipbirds, logrunners, Australo-Papuan babblers (to distinguish them from scimitar babblers and their allies), fairy-wrens, honeyeaters, acanthizids (thornbills, gerygones and allies), whistlers, woodswallows, butcherbirds, and more. Mostly beyond Australia, an even larger group of passerine species, recently termed the Passerides, evolved and mostly in the Northern Hemisphere. One of its earliest branches, however, is the lineage of Australo-Papuan robins, and could even be largely descended from an ancestor of that group itself. Some Passerides have later ('secondarily') returned to and radiated within Australo-Papua, grassfinches being a fine example. The true thrushes, white-eyes, swallows and martins, reed-warblers, cisticolas, and grassbirds are all in this category. Many other Passerides are only convergently similar to birds in the Australian region. Thus, treecreepers and creepers are not closely related to each other, and fairy-wrens are not at all close to true wrens, for example. The 1935 worker especially might need to sit down at this point.

Down to genus

We have seen that at higher levels of bird classification, research most often clarifies which clearly defined group is related to which other clearly defined group, rather than altering the membership of the groups themselves. What of the genus-level? Why so many perhaps unfamiliar generic names in the 2017 *Guide*? Examples will show that, in essence, much the same reasons apply.

Since 1975, several generations of ornithologists have become accustomed to some 20 species of honeyeaters making up the genus *Lichenostomus*. Not until 2011 did the first of several DNA studies tackle this and find that *Lichenostomus* in Australia was made up of at least seven different groups or lineages (Nyari and Joseph 2011; Joseph et al., 2014); the total number is eight, now that one key New Guinean species, formerly known as *Oreornis chrysogenys*, has finally been included in DNA studies (Marki et al., 2017). Further, at least six generic names were needed for the Australian species. Why? Five of the seven Australian groups were scattered throughout the full honeyeater phylogeny and were not each other's closest relatives, and so needed five generic names. The remaining two were indeed each other's closest relatives. They could validly be placed in a single, sixth genus or divided into a sixth and a seventh. The argument was made that because they are such distinctive lineages which diverged several million years ago, assigning them to two genera *Ptilotula* and *Gavicalis* ("plumed" and "fasciated" honeyeaters, respectively) made sense. Consider, for example, how different are the "plumed" Yellow-plumed and "fasciated" Singing Honeyeaters. The habit of using a broad *Lichenostomus* is dying hard, but die it must. Incidentally, the New Guinean species that was last to be included in DNA studies belongs in the genus *Microptilotis*, itself split from *Meliphaga* (Joseph et al., 2014; Marki et al., 2017). And, last but not least, two species remain in *Lichenostomus*. One is the species on which *Lichenostomus* was based, the Purple-gaped Honeyeater *L. cratitius*, and the other is its closest relative, the Yellow-tufted Honeyeater *L. melanops*.

Still with honeyeaters, three species having black-and-white plumages (Pied, Black, Banded) were long placed in *Certhionyx*. They are not each other's closest relatives and must be classified in three different genera (Joseph et al., 2014).

Monarch flycatchers all look like monarch flycatchers, so they belong in the genus *Monarcha*. Right? No. DNA showed that *Monarcha*, like *Lichenostomus*, fell into groups or lineages of species that are *not* all each other's closest relatives (Andersen et al., 2015). So, again, *Monarcha* is restricted to the lineage that includes the single species on which *Monarcha* was first based, the Black-faced Monarch *M. melanopsis*. *Monarcha*, then, is more closely related to Pacific island genera such as *Chasiempis* and *Pomarea* than to other Australian and New Guinean species formerly placed in *Monarcha*. So, those other species need other genera and they now fall into two genera, *Symposiachrus* and *Carterornis*. And, finally here, the Australian Magpie-lark and its close relative the Torrent-lark of New Guinea are a part of the monarch flycatcher radiation.

The importance of all this is not that names have changed — that's the least of it. It is that through systematics we grow to appreciate the spectacular evolution of even our most familiar birds. Systematics directs taxonomic changes, the details of which are governed by the rules of zoological nomenclature. All of this enhances what you see when observing a bird!

The species level — higher hanging taxonomic fruit

Discovery of the Eungella Honeyeater, the last unquestioned species of Australian bird to be discovered *and* scientifically described (Longmore and Boles, 1983), did not mean the end of species-level taxonomy for Australian birds. Modern research documents the complex evolution still occurring at the species-population level, within and among species. We interpret this through 'lenses' of different biological characters (DNA sequences, plumage, vocalizations, and more). Interpretation through one such lens coupled with one of many ways of defining a species might suggest two populations share a gene pool and that they should be treated as one species. Another lens and another way of defining a species might suggest that they are well and truly different lineages in the avian phylogeny and that two or more species should be recognized. Reconciling these different lenses using a taxonomic system devised before Charles Darwin is akin to feeding rocket fuel to a horse pulling a cart: things may collapse! By another analogy, seeing present-day diversity through two different lenses of biological characters is akin to slicing a cake two different ways. Both have their validity but which will we follow?

Fortunately, one category of problem is simplest to resolve and again hinges on 'tree-thinking'. Until 2010, the White-naped Honeyeater *Melithreptus lunatus* was thought to comprise eastern Australian *M. l. lunatus* and south-western Australian *M. l. chloropsis*. DNA shows the eastern birds are more closely related to the Tasmanian endemic Black-headed Honeyeater *M. affinis* than to the western birds (Toon et al., 2010). We infer that the white nape-band was present in the ancestor of *Melithreptus* honeyeaters but has been lost in *M. affinis*. We could treat all three as one species (sensible? you decide!) or the western birds *must* be a separate, third species, *M. chloropsis*. In this case, the DNA evidence has in effect argued that it is time to correct and update an earlier way of thinking based on similarities and differences.

In Golden Whistlers, *Pachycephala pectoralis*, separate populations in Western Australia and, mostly, South Australia characterized by cinnamon-bellied females were assigned to the subspecies *Pachycephala pectoralis fuliginosa*. The significance of subtle differences between them in plumage had been debated since the 1950s. DNA shows that those two isolated or at best tenuously connected populations are not each other's closest relatives. Further, the eastern (mostly South Australian) populations of "*P. p. fuliginosa*" are not genetically separate using the markers studied to date from other eastern Australian populations (Andersen et al. 2014; Joseph et al., 2014). Most critical of all, the western populations of "*P. p. fuliginosa*" are likely more closely related to another species of whistler altogether and so may not even be the closest relative of eastern Australian Golden Whistlers at all. Again, the cinnamon-belly of females in south-western and some parts of south-eastern Australia may be an ancestral character lost in some, but not all, present-day populations. Taxonomically, the south-west Western Australian populations must become a separate species, which happily does have some subtly distinct plumage characteristics, and rules of nomenclature dictate that it be known as *Pachycephala occidentalis*. Further study is needed to address how the re-defined *P. pectoralis fuliginosa* mainly of South Australia relates to other eastern Australian Golden Whistlers.

What of cases like the Crested Shrike-tit's "Eastern", "Northern" and "Western" forms where slight plumage differentiation (as we perceive it) between isolated populations has long led ornithologists to say, "They are just subspecies"? These seem thornier, not so much because the various birds are again geographically isolated from each other, but because debate about how many species there are has never really settled on any one prevailing view. Why? I suggest this is partly because there is often an unspoken undercurrent of thinking in cases like the shrike-tits concerning how we should interpret similarities and differences. That is, to us they look so similar that the notion of them being separate species seems harder to digest despite any differences and similarities in vocalizations or behaviour. If some other differentiating character appears, such as vocalizations, coupled with whether their ranges overlap naturally or not, two species may become accepted. Think of the very similar-looking Chirruping and Chiming Wedgebills, which sound so very different and occupy different habitats where they approach each other geographically that their recognition as two species now goes unremarked. DNA evidence supports this (Toon et al., 2013). Critically needed research on isolated populations like the shrike-tits won't change the reality of their existence: birders should want to see and hear them all! As with the *Melithreptus* honeyeaters and whistlers, research is needed to reveal one or other of a fairly small number of predictable patterns of relationships among them. The problem then is in interpreting patterns among such isolated populations under the Biological Species Concept, ornithology's dominant definition of a species since the mid-20th century. It requires that we venture to supposition at the edge of science. Does it matter whether they could interbreed if they came together, which clearly they aren't about to do? Does the degree of differentiation between some other closely related pair guide us? I ask, "Is this the best our science can do today?" I hope not. Alternatively, in the case of such isolated populations about which there is taxonomic debate, we *are* interested in how they are related to each other in the avian phylogeny, how similarities and differences in other traits can be interpreted in a framework of well-understood evolutionary relationships and, perhaps, a different species concept, whether gene flow has ceased among them, and whether they are continuing to diverge even if there is gene flow, however occasional. We can test that using data and analyses of those data that can be repeated. That *is* science. So, I suggest that the species or subspecies question is interesting for very different reasons these days but, nonetheless, debate about it won't go away, especially where isolated populations are concerned. I suggest that it will often be more interesting and useful to first examine how the isolated populations are related to each other. Then we can ask whether some phenomenon like gene flow, say between two and not a third, is affecting their divergence. Finally, does all of that dictate an alternative approach to classification?

An example that involves present-day isolated populations and past gene flow will help here. Debate has long been whether Grey and Silver-backed Butcherbirds are one or two species. We now know that Silver-backed Butcherbirds are the closest relatives of a third bird, the Black-backed Butcherbird. The Grey Butcherbird is, in turn, the closest relative of the other two. Recent research (Kearns et al., 2014) gave a twist: genes from Grey Butcherbirds entered into eastern populations of Silver-backed Butcherbirds, probably some 20,000 years ago, and have now spread west through Silver-backed Butcherbirds. Only in the westernmost parts of Silver-backed's range is the relevant piece of DNA still in its "pure" Silver-backed Butcherbird form, and closest to that of Black-backed Butcherbirds. Silver-backed and Grey cannot be regarded as the same species. Hybridization and gene flow has, we argue, occurred among species that are not closest relatives, that pattern of relationships having been established much earlier in butcherbird evolution. In other words, hybridization need not mean that the birds involved *are* closest relatives. A classification reflecting evolutionary history is *not* achieved by making Grey and Silver-backed the same species because of past gene flow. A very similar example concerns the Pale-headed, Northern, and Eastern Rosellas. Pale-headed and Northern Rosellas are closest relatives and can be recognized as two species. Genes from the Pale-headed appear to have extensively "infiltrated" Eastern Rosellas of the mainland but not Tasmania. Eastern Rosellas must nonetheless be regarded as a third species (Shipham et al., 2015, 2017). Recognition in the 2017 *Guide* of the Copper-backed Quail-thrush as a species separate from the Chestnut Quail-thrush arose from an example of this kind of research into past gene flow having been explored (Dolman and Joseph, 2016).

By telling us about the phylogeny — the evolutionary history or evolutionary footprint of a species or population — we can learn something about biogeography: how species evolve as landscapes also evolve and climates change. They tell us that the Tasmanian population of Eastern Ground Parrots, for example, still share genetic diversity with mainland eastern Australian populations despite current isolation by Bass Strait. The Western Ground Parrot, however, is weakly but consistently differentiated in plumage and shares no diversity with any eastern birds for the piece of DNA so far studied (Murphy et al., 2011). Recognizing these as two species says that until we can demonstrate genetic connections between western and eastern populations, we interpret the available data as favouring the idea ('hypothesis') that they are two lineages not exchanging genes and that we should call them two species. Further, we can suggest why they look so similar: strong natural selection for camouflage to avoid predation. Indeed, the unquestionably different species, the Night Parrot, is in many ways not so different in appearance, so its plumage, too, is probably under similar long-term evolutionary pressure. This reiterates potential traps of relying on differences in plumage. Australian populations of the Spectacled Monarch most definitely are two genetic groups with respect to mitochondrial DNA, but these in no way match geographical structure in their plumage variation. Research is still in progress to examine why this is so; the answer, I suspect, will again involve how well we can understand intricacies of the population genetics of the species in its past.

Lessons have been learned about how important it is to understand what we might call DNA's own natural history. DNA studies of two pairs of Australian birds well illustrate one potential interpretative trap. One pair of species is the White-browed and Masked Woodswallows, and the other is the Grey and Chestnut Teals. What we have learned from these two pairs concerns multiple species that have diverged from their most recent common ancestor only very recently in evolutionary terms. It may be that we can see (or hear) very clearly that they are distinct species. Some of the DNA we study, especially mitochondrial DNA, may not have "caught up" yet, as it evolves more slowly than, say, plumage and the genes controlling plumage differences. Certainly, in the teals and perhaps in the woodswallows, those genes may well even be located on the sex chromosomes, whereas their pool of diversity for mitochondrial DNA may still essentially be that of their common ancestor (Joseph et al., 2006; Dhami et al., 2016). Alternatively, testing for a role of natural selection at the level of DNA itself can be critical. This has, we believe, led to the best approach to understanding some truly remarkable patterns of genetic diversity in the Eastern Yellow Robin. Within that species, there is a geographically structured but extraordinarily deep genetic break in mitochondrial DNA diversity between two groups of populations. The magnitude of this break is more typical of that seen between genera than within a species. We have argued, however, that it is best interpreted as evidence of selection on mitochondrial DNA, and that there is no need to alter subspecies or even species-level classifications (Morales et al., 2015, 2017).

Geographical overlap of migratory and non-migratory populations also needs disentangling by field, museum and laboratory work. The mystery of how many species should be recognized in the Cicadabird, which by our current understanding also occurs widely outside Australia, is a fine example (Pedersen et al., in press).

I hope all this gives a taste of the complexity of these species-level problems and why they will be around for a while yet. Each case will be different. Patterns of relationships and what gene flow does or does not mean with regard to whether it is stopping divergence between two populations will be critical. The 2017 *Guide* is a treasure chest of the problems waiting for study. How many species are in the Purple Swamphen, Spinifex Pigeon, Red-tailed Black-Cockatoo, Helmeted Friarbird, Spectacled Monarch and Cicadabird, to name a few? Are the three *Polytelis* parrots (Superb, Regent and Princess) more closely related to each other than one or two of them are to other parrots? While reassuring our friends from 1935 and 1975 that we have made strides, they'd delight in reminding us of the old maxim — the more we learn, the more questions we find. And that is as it should be.

Appendix

Scientific names of species mentioned but omitted in the text for clarity of reading

Australian Brush-turkey *Alectura lathami*
Plains-wanderer *Pedionomus torquatus*
Magpie Goose *Anseranas semipalmata*
White-browed Crake *Amaurornis cinerea*
Spotted or Australian Crake *Porzana fluminea*
Australian Spotless Crake *Zapornia tabuensis* (*Porzana tabuensis* in some texts)
Baillon's Crake *Zapornia pusilla* (*Porzana pusilla* in some texts)
Grey Teal *Anas gracilis*
Chestnut Teal *Anas castanea*
Australasian Purple Swamphen *Porphyrio melanotus* (*Porphyrio porphyrio* in some texts)
Hoatzin *Opisthocomus hoazin*
Spinifex Pigeon *Geophaps plumifera*
Budgerigar *Melopsittacus undulatus*
Red-tailed Black-Cockatoo *Calyptorhynchus banksii*
Superb Parrot *Polytelis swainsonii*
Regent Parrot *Polytelis anthopeplus*
Princess Parrot *Polytelis alexandrae*
Pale-headed Rosella *Platycercus adscitus*
Northern Rosella *Platycercus venustus*
Eastern Rosella *Platycercus eximius*
Eastern Ground Parrot *Pezoporus wallicus*
Western Ground Parrot *Pezoporus flaviventris*
Night Parrot *Pezoporus occidentalis*
Grey Grasswren *Amytornis barbatus*
Eungella Honeyeater *Bolemoreus hindwoodi*
Bridled Honeyeater *Bolemoreus frenatus*
Yellow-plumed Honeyeater *Ptilotula ornata*
Singing Honeyeater *Gavicalis virescens*
Helmeted Friarbird *Philemon buceroides*
Scrub-tit *Acanthornis magna*
Copper-backed Quail-thrush *Cinclosoma clarum*
Chestnut Quail-thrush *Cinclosoma castanotum*
Western Whipbird recently advocated to be *Psophodes nigrogularis* and *Psophodes leucogaster*
Chirruping Wedgebill *Psophodes cristatus*
Chiming Wedgebill *Psophodes occidentalis*
Crested Shrike-tit *Falcunuclus frontatus*
Spectacled Monarch *Symposiachrus trivirgatus*
Cicadabird *Edoliisoma tenuirostre*
Grey Butcherbird *Cracticus torquatus*
Black-backed Butcherbird *Cracticus mentalis*
Silver-backed Butcherbird *Cracticus argenteus*
White-browed Woodswallow *Artamus superciliosus*
Masked Woodswallow *Artamus personatus*
Eastern Yellow Robin *Eopsaltria australis*

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Creative foundations. The Royal Society of New South Wales: 1867 and 2017

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Abstract

There have been two key foundations in the history of the Royal Society of New South Wales. The first at its creation as a Royal Society in 1867, shaped significantly by the Colonial savant, geologist the Rev. W. B. Clarke, assisted by a corps of pioneering scientists concerned to develop practical scientific knowledge in the colony of N.S.W. And the second, under the guidance of President Donald Hector 2012–2016 and his counsellors, fostering a vital "renaissance" in the Society's affairs to bring the high expertise of contemporary scientific and transdisciplinary members to confront the complex socio-techno-economic problems of a challenging twenty-first century.

"This country is so dead to all that concerns the life of the mind", the scholarly newcomer the Rev. W. B. Clarke wrote to his mother in England in September 1839 shortly after his arrival in New South Wales (Moyal, 2003, p. 10). But a man with a future, he quickly took up the offer of the editor of *The Sydney Herald*, John Stokes, to contribute to the paper on science, and with John Fairfax's proprietorship of the renamed *Sydney Morning Herald* in 1841, Clarke launched a series of twenty unsigned articles entitled `Meteorology as applicable to Australia' in January 1842 and followed it in July–December 1842 with a second unsigned series,`*Notitiæ Australasianæ'*, in which he sought to bring local scientific discoveries before the public and to call upon colonists "through the habit of observation" to make useful contributions to natural science. Thereafter across the next two decades Clarke became *The Sydney Morning Herald*'s major contributor of articles, letters, scientific reports and editorials, (sometimes anonymous, or with cryptic signatures) on a span of topics that embraced geology, meteorology, climate, mineralogy, the natural sciences, earthquakes, volcanoes, comets, storms, inland and maritime exploration and its discoveries which gave singular impetus to the newspaper's role as a media pioneer in the communication of science (Organ, 1992).

With only three scientific institutions in mid-century New South Wales — the Royal Botanic Gardens, the Parramatta Observatory and the Australian Museum — the scientific community was small. The Australian Philosophical Society, formed in 1850 (as a post-event of Governor Brisbane's fleeting Philosophical Society of Australasia of 1821), was renamed the Philosophical Society of New South Wales in 1855 and gained some vigour under the presidency (1856-61) of the scientifically-minded Governor-General of the Colonies, Sir William Denison. Yet by 1866, stirred by the establishment of the new universities of Sydney (1852) and Melbourne (1855), the growth of museums and observatories, and the advent of a major geological survey in gold-rich Victoria, a view gained currency that the historical concept of a `Philosophical' society no longer reflected a community with diverse scientific interests and an expanding government commitment to science. With the assistance of the Governor, Sir John Young, the Royal Society of New South Wales gained Royal assent in 1866 and was formally established in 1867, the third society in Australia to acquire the Royal title, following the Royal Society of Van Diemen's Land in 1832 (renamed Royal Society of Tasmania in 1911), and the Royal Society of Victoria in 1859. In this forward thrust, Clarke, a long-time councillor and Vice-President of the Philosophical Society, was a prime mover.

By the end of the 'fifties William Branwhite Clarke was the most strategically placed scientist in the Colony. Arriving from Britain to take up his profession as an Anglican clergyman in Sydney in May 1839, he had received geological training with Adam Sedgwick at Cambridge University, published papers on aspects of British and Continental geology, was a Fellow of the prestigious Geological Society of London and arrived in the Colony as the first trained geologist to settle in Australia. While he earned his way as a churchman, Clarke early began his pioneering geological excursions, publishing papers in Britain and the Colonies and communicating new findings to the Sydney press. Importantly, through his service to Government on a variety of committees on artesian water and gold and, notably, through his role as Geological Surveyor appointed by government in 1851–53 to conduct surveys of the mineral wealth of New South Wales — excursions that yielded twenty detailed reports published by the Legislative Council of New South Wales and distilled through *The Sydney Morning Herald* — Clarke had emerged as a leading savant, a prominent player in negotiating science, and a household name.

He had become, in effect, what British historian of science, James Moore, defined in Britain's scientific community, as the owner of intellectual "scientific credit", one who, offering support and advancement to others, carried "symbolic capital" (Moore, 1996). As a researcher, Clarke had also developed strong connections outside the Colony as an honorary member of the New Zealand Society, a life Fellow of the Royal Geographical Society, a member of the Société Géologique de France, and, strikingly, had fostered and continued to foster a substantial correspondence with intercolonial and international scientists in the natural and physical sciences. Combining many parts, he was elected senior Vice-President of the new Royal Society of New South Wales and, at the age of 69, played a key part in the Society's formative first seven years.

One hundred and eight men signed the Membership List of the new Royal Society in 1867. Their collective company represented a wide community of men of differing pursuits and ages who shared a sense of buoyancy at the opportunities for fresh initiatives and knowledge in the Colony. Made up of senior civil servants from the Colonial Departments of Lands, Works, Mining, Land Titles, Telegraph, Publishing, the Colonial Secretary, the Attorney-General, the Colonial Architect, the Surveyor-General, and professional scientists from Sydney Observatory, the Botanic Gardens, the Australian Museum and the Mint, two professors from Sydney University, they also included independent astronomers, entomologists and natural scientists, an array of physicians and clergymen with scientific interests, several MLC's and MLA's and two staff members from *The Sydney Morning Herald*. They hence included an association of players both involved professionally in aspects of scientific and technological progress in New South Wales, together with a corps of independent participants with research publications and overseas experience and a lively interest in the natural sciences (*Transactions*, 1867, 1, pp. xi–xiii)[1].

It was to this newly founded learned society that W. B. Clarke gave the Inaugural Address on 6 July 1867 as first Vice-President, a position he would hold until his death in 1878. Considering the concept of a "philosophical" society as no longer alone appropriate to national ends, he offered a broad and practical vision for the future:

> "Let us perform our own proper work [he said], not caring whether we ever arrive at complete knowledge of the methods by which the Universe was formed and perfected. We have before us in this Colony a vast region, much of which is still untrodden ground. We have, as it were, a new heaven for Astronomy and a new earth for Geology. We have climatical conditions of the Atmosphere, which are not to be viewed by us merely as phenomena interesting to the Meteorologist. We have facts to accumulate relating to Droughts and Floods which have a deep financial and social importance. We have a superficial area which may engage the attention of Surveyors, Agriculturalists, and Engineers for years to come. We have unrevealed magazines of mineral wealth in which Chemists and Miners may find employment for ages after we shall all have mingled with our parent earth. All that we have to trouble ourselves with, is the right interpretation and development of these physical riches, so bountifully spread around and beneath us for our investigation and use" (Clarke, 1867, p 26).

It was relevant that in the decade when *The Origin of Species* was in discussion in the Colonies and Clarke himself was in correspondence with Charles Darwin, his conclusion was open and germane. "We must strive to discern clearly, understand fully, and report faithfully; to love truth in things physical as in things moral; to adjure hasty theories and unsupported conjectures; where we are in doubt not to be positive; to give our brother observer the same measure of credit we take to ourselves; not striving for mastery, but leaving time for the formation of the judgment which will inevitably be given, whether for or against us, by those who come after; contented if we are able to add but one grain to that enduring pyramid which is now in course of erection as the testimony of Nature to the truth of Revelation."[2]

Within the Colony's scientific activities, astronomy was in the ascendant. Ever since Governor Brisbane's establishment of the Parramatta Observatory in 1821, the resulting publication of the first major star catalogue of the southern hemisphere, *The Parramatta Catalogue of 7,385 Stars* (1838), had focused international attention on Australian astronomy and fostered its development. With the closure of the Parramatta

[1] See http://www.biodiversitylibrary.org/page/40522032

[2] Like many key scientists in the Australian Colonies and in Britain and the United States, Clarke remained a `Separate Creationist' all his days. Corresponding with Darwin in August 1861 on receipt of *The Origin*, the first page of his letter of greeting is missing from the Darwin Correspondence held in Cambridge. The full letter relates to geological findings (Moyal, 2003, vol 1. pp 551-2) with the evolutionist.

Observatory in 1848, work began in 1856 on construction of the Sydney Observatory and the Rev. William Scott, a Cambridge wrangler and lecturer in mathematics from Sydney Sussex College, Cambridge, was appointed Government Astronomer. Scott oversaw the Observatory's construction at Flagstaff Hill, began meridian observations on the position of certain stars, and with an Equatorial telescope of a 7.25-inch aperture began observations of comets (ADB, 6).

Both Scott and the brilliant locally born astronomer, John Tebbutt, Jr., were early members of the Royal Society. Exploring the southern heavens with an ordinary ship's telescope and sextant from his home at Windsor, New South Wales, 27-year-old Tebbutt had the grand experience of discovering the "great comet" of 1861 and enlarging the reputation of Australia's astronomical science. Tebbutt built his own modest observatory at Windsor, independently maintaining a remarkable series of accurate descriptions on comets, occultations on stars by the moon, eclipses, transits of Jupiter's satellites, variable stars and double stars, and the positions of minor planets, all of which were invaluable to world astronomers. He proved a prolific sharer of his scientific knowledge, reporting his cometary observations in 61 research papers and in the press, publishing *Meteorological Observations made at the Private Observatory of John Tebbutt Jnr.*, and producing some 300 papers in scientific journals. Tebbutt won the title of Australia's greatest nineteenth-century astronomer (Bhathal, 1993; Moyal, 1976, pp 133–5).

Drawing on experience at the Royal Observatory, Cape of Good Hope, and as lecturer in mathematics at Kings College, London, George R. Smalley succeeded Scott as Government Astronomer in 1864. He shared the Vice-Presidency of the Society with Clarke and contributed several papers on astronomy to the *Transactions* before his unexpected death in 1870 (ADB, 5). The astronomers were served by the expertise of another Society member, the scientific instrument maker, Angelo Tornaghi. Born in Milan, Tornaghi came to Australia in 1858 to supervise the installation of instruments at the Flagstaff Observatory, and set up a scientific instrument, optical and clock-making business in Sydney, which became a major source of expertise supplying instruments and building and servicing telescopes for the Colony's professional and amateur astronomers.

The fields of biology and zoology were also richly represented in the Society. Dr George Bennett, a practising zoologist in the Colony since 1836, had trained as a medical doctor at the Hunterian School of Medicine, London, where he began a lifelong friendship with fellow student Richard Owen. His research centred on the kangaroo and other marsupials, and the monotremes; he published *Wanderings of a Naturalist in New South Wales, Batavia, Singapore and China* (1834) and *Gatherings of a Naturalist in Australasia* (1860). Settled in Sydney as a physician, Bennett served as Secretary of the Colonial Museum 1836–42. His long life of field research exemplified the vital link forged between science at the periphery and the metropolis in his sustained contribution of biological specimens of marsupials, monotremes, and the fossil remains of extinct marsupials to Professor Owen, the towering leader of British comparative anatomy and palaeontology (Newland, 1991; Moyal, 1976, p 896).

By contrast at the Australian Museum, the German zoologist, Johann Gerard Krefft, marked an independent-minded researcher and author who sought local authority for his Australian work. Emigrating to the Victorian goldfields in 1857, he became Curator at the Australian Museum in 1864. A Fellow of the Linnaean Society of London and a correspondent of the Zoological Society of London, Krefft was the author of *Snakes in Australia* (1869) and *Mammals of Australia* (1871) and had the distinction of being an early and articulate Darwinian in Australia (ADB, 5; Moyal, 1976, pp 822–3). Charles Moore, trained at Kew Gardens and appointed as Colonial Botanist in New South Wales, developed a scientific herbarium at Sydney and as Director of the Botanic Gardens became an active member of the Royal Society's Council (ADB, 5).

The Society's membership in applied science evolved through staff members from the Sydney Branch of the Royal Mint. Its first Deputy Master, Captain Edward Ward, appointed in 1854, became an influential figure in Sydney, a member of the Philosophical Society of New South Wales, and a Corresponding member of the Royal Society when he moved in 1869 to establish the Melbourne Branch of the Royal Mint.[3] Legal tender was at last established in the Colonies in 1857.

Robert Hunt, Deputy Master from 1865, was a Society member, while Dr Adolph (Carl) Leibius, trained in chemistry in Germany at the University of Heidelberg and in analytical and assaying chemistry in London, joined the Mint in 1859 and, a contributor to the *Transactions* with his colleague and Fellow member Francis Miller, was later destined to play an active role as Honorary Secretary of the Royal Society. There, too, was Thomas Mort, businessman and entrepreneur, who from 1866 financed experiments and ideas in refrigeration machinery (ADB, 5).

Civil servant members of the Society exhibited a range of talents. The Colonial Architect, James Barnet, a man of striking creative achievement across his long career, 1865–90, built courthouses, police stations, post offices including Sydney's distinguished General Post Office, the Customs House, the Public Library, the Medical School of the University of Sydney, and finally Sydney's famous International Exhibition building, the Garden Palace Building, made of glass and iron, to showcase the Colony's resources and activities. His buildings, it was said, "took the public taste". Of eclectic interests, Barnet published *A Monograph of Australian Land Shells* (1868) (ADB, 3).

E. C. Cracknell, Superintendent of Telegraphs in New South Wales, brought the transformative new technology of the telegraph to the Colony. Emigrating to Australia from Britain as technical assistant to the newly appointed Astronomer of South Australia, Charles Todd, in 1855 Cracknell moved to Sydney as assistant superintendent in 1858. The Colony was soon ringed about with electric telegraph lines — that `Most Wonderful Invention' — while, as Superintendent from 1861, Cracknell built connections with the stretching intercolonial telegraph networks and in January 1876 officiated at the joining of the cable connection from Botany Bay to New Zealand to link the seven "Australasian Colonies".

The medical contingent in the Society, numbering some eight doctors including Dr Bennett and the respected Rev. Dr John

[3] His creative first Assayer, and member of the former Society, was the remarkable young William Stanley Jevons, whose rich, if reclusive, intellectual period spent in Sydney from 1854–59 led to his distinguished career as an economist (both theoretical and applied) and social theorist in England (Marks, 2016).

Dunmore Lang, held other engaged participants. Dr James Cox FRCS, pastoralist and merino breeder (an editor of *The Stud Book of New South Wales*), founded the local Linnean Society, was elected a Fellow of the Linnean Society of London, and was a dedicated conchologist, publishing several editions of that popular colonial topic, *Monograph on Australian Land Shells* (1858) (ADB, 3). Dr John Le Gay Brereton, poet and prose writer, was also numbered among the members while Charles Nathan, trained at Westminster Hospital School of Medicine, founded the New South Wales Branch of the British Medical Association, was a member of the N.S.W. Medical Board, a founding member of the University Senate, and was the doctor called upon when the Duke of Edinburgh was wounded in an assassination attempt in March 1868 (ADB, 5). Edward Bedford FRCS, surgeon, politician and public servant during an eminent medical career in Hobart, emigrated to Sydney in 1863 where he was appointed medical adviser to the New South Wales government. He joined the Society in 1864 and contributed several papers to the *Transactions* while also serving from 1867–74 as Honorary Treasurer. (ADB, 3, obituary; Clarke, 1876, p 11).

Most important to the character of the new Society, however, was the influence of the University. From the beginning, Sydney University took its cue from London University, with its strong emphasis on scientific chairs, planning four in mathematics; anatomy, physiology and medicine; chemistry and experimental physics; and natural history. To the vocal disappointment of T. H. Huxley, an eager candidate for the proposed but discarded natural history chair (Moyal, 1976, pp. 98–100). John Smith M.D., lecturer in chemistry from Aberdeen University, was the first academic science appointment as Professor of Chemistry and Experimental Physics at Sydney in 1852, together with the first Professor of Mathematics, Morris Birkbeck Pell, 1852–76. Smith's research interests were in water analysis and educational policy and he served on many commissions. Pell's teaching in Mathematics underwrote its teaching as a compulsory subject in the Bachelor of Arts degree, and its impact proved crucial. Henry Chamberlain Russell, born and educated in Maitland, New South Wales, graduated in physics and chemistry with a BA degree in 1858 and was at once appointed "computer" at the Sydney Observatory, rising to Acting Director 1862–4, and Government Astronomer on Smalley's death in 1870. As such, he was the first graduate from Sydney University to rise to eminence and influence in Colonial science. Russell's work in astronomy, meteorology and geophysical science was far-reaching. Equipping a huge number of meteorological stations in New South Wales with his privately designed self-recording instruments, he based his pioneering papers on Australian weather and the cyclic behaviour of climate on this accumulated mass of evidence. He also published the first Australian Weather Map in *The Sydney Morning Herald*, 3 February 1877[4]. In astronomy, Russell gained international prominence in organizing Australia's observations of the transit of Venus in December 1874 and in his pioneering stellar and lunar photography of the Milky Way and Magellanic Clouds and large stars. A formidable contributor to the Royal Society, (he published some 69 papers in its *Journal* and numerous works elsewhere), he followed Clarke's steps in becoming a three-time Vice-President of the Society. He was elected a

4 See http://trove.nla.gov.au/newspaper/article/13389140/1438919

Fellow of the Royal Society of London in 1881 (ADB, 6; Bhathal, 1991; Moyal, 1976, pp 832–3).

In December 1866, Dr A. M. Thomson, one of London University's first doctors of science, with experience at the Royal School of Mines, arrived at Sydney University as Reader in Geology, marking an important extension in science. Working also as assistant in chemistry to Professor Smith, he published a number of pioneering geological papers and a *Guide to mineral explorers in distinguishing minerals, ores and gems* (1869) and was posted as the first Professor of Geology at the University in 1870 where he taught "very up-to-date- courses", gave popular public lectures and opened science teaching to senior students at Sydney Grammar School. Thomson was rapidly recruited to the Royal Society where he became a member of Council in 1870 and a key contributor. His brilliant young life, however, was cut short as an outcome of his work with Gerard Krefft in the excavation and examination of fossils of extinct marsupials in 1869 in the damp Wellington Caves (Moyal, 1976, pp. 206–211). He died in 1871, a significant loss to the Colony, the Society, and to Clarke, for whom, through their close geological collaboration, he had become a "scientific son."

Such, in sum, was the diverse company of the Royal Society when it gathered its members together to begin a new creative epoch in its affairs.

It fell to George Smalley, the second Vice-President, to indicate the progress made in the Society in its first year in his Opening Address to members on 3 June 1868. With the new name, he declared "we are exhibiting signs of fresh vitality". Smalley pressed the value of "meeting in a social manner" and judged that in the long history of establishing societies for the advancement of science, art and literature, "In a young community, a society such as this is the only one likely to be appreciated in promoting the advancement of art and science with an energy adequate to meet the requirement". "Great things", he predicted "grow out of small beginnings", and he hoped that women, whom he considered "neither uninterested nor unappreciative of science" and "not incapable of understanding it", would not only "grace with their presence at the Conversationes of this society, but sometimes attend the ordinary meetings" (Smalley, 1868, p. 8). It was a view that took root in the establishment of the periodic social public assemblies that were held by the Society from 1873 and greatly enlarged its audiences.

Volume 1 of the of Society's *Transactions* of their first year of meetings was published in 1868[5]. With papers from Clarke, Smalley, Krefft, and Pell, it covered topics as wide as 'On the Auriferous and other Metalliferous Districts of Northern Queensland', 'The Mutual Influence of Clock Pendulums', 'The Vertebrates of Tasmania, recent specimens and fossils', and 'On the Rates and Expectation of Life in New South Wales compared with England and other Countries'. Volumes 2 and 3 of the *Transactions*, presenting papers of 1868-9, extended the range[6]. There was Dr Alfred Roberts `On the Hospital Requirements of Sydney', Clarke `On the Causes and Phenomena of Earthquakes, especially in relation to the shocks felt in New South Wales, and in other provinces of

[5] See https://royalsoc.org.au/council-members-section/73-jprocrsnsw-vol-1

[6] See https://royalsoc.org.au/council-members-section/74-jprocrsnsw-vol-2 and https://royalsoc.org.au/council-members-section/75-jprocrsnsw-vol-3

Australasia', Smalley's `On the value of Earth Temperatures', Russell's `Tables for Calculating the Humidity of the Air', Smith `On the Water Supply of Sydney' and 'On the results of the Chemical Examination of Waters for the Sydney Water Commission', Dunmore Lang 'On the Origin and Migration of the Polynesian Nation', Edward Cracknell on the Electric Telegraph, mathematician Martin Gardiner's contributions on 'New Theorems in the Geometry of Three Dimensions' and 'Improving Solutions of Problems in Trigonometrical Surveying', F. B. Miller 'On Refining Gold by Means of Chlorine Gas', A. Leibius 'On a New Apparatus for Reducing Chlorine of Silver' and Alexander Thomson's 'Notes on the Geology of the country around Goulburn'. Investigative advances had been made and serious scientific information transferred. By 1869 forty new members had joined the Society.

W. B. Clarke's part in the expansion of the Society's new mode drew strongly on his reputation and continuing scholarly work. Touching 70, his nets never dried; he remained the senior geologist in the country. Retiring from his large parish of St. Thomas's Church, North Sydney in 1870, he became deeply engaged in bringing his long researches and collections on the stratigraphy of the country to fruitful conclusion in a lengthy correspondence with the distinguished Belgian palaeontologist Laurent de Koninck, Professor of Palaeontology and Chemistry at Liége University, conducted entirely in French.[7]

In addition to his own work, Clarke used his "scientific credit" to influence the Queensland Government to appoint two geological surveyors, dropped from the disbanded Geological Survey under Alfred Selwyn in Victoria, to new survey posts in Queensland — Christopher Aplin in Southern Queensland and Richard Daintree in the North — where their pointers to gold proved invaluable in stimulating the gold rushes in that Colony. Their geological findings along with that of scattered others found their way as major contributions to knowledge through the Anniversary Addresses which Clarke, as Vice-President, delivered to the Society and in the many papers he wrote for the *Transactions*. Drawing on a substantial survey of new information on diamonds and other minerals, he reported in his Vice-Presidential Address of 22 May 1872, "We have now evidence that Eastern Australia is what I have often stated, one vast field of mineral wealth. From north to south, and from the coast to the 41st meridian, the western boundary of New South Wales, we know that coal, gold, copper, tin, and, in many places, lead, and other minerals of less local importance, are found in abundance" (Clarke, 1872, p 38).

Clarke was also a great encourager of younger members in other disciplines. H. C. Russell wrote to him calling on his expertise on weather, climate, floods, storms, tides and coastal elevation and the varying appearance and disappearance of Lake George. Informing letters also came to him from Gerard Krefft, to whom he gave strong support during the 1870's, while the warm collegiate correspondence and exchange

7 From 1864-77 de Koninck undertook the classification of Clarke's Devonian, Silurian and Carboniferous specimens, lists of which Clarke published as an Appendix to the 4th edition of his *Remarks on the Sedimentary Formations of New South Wales*, 1878. De Koninck's *Recherches sur les fossiles palaéozoic de la Nouvelle-Galles du Sud (Australie)* 1876-77 describing some 266 of Clarke's fossil specimen was finally published in English by T. W. E. David, Mrs David and W. S. Dun in 1898 (Moyal, 1976, p 668).

Clarke enjoyed with Alexander Thomson underscored his role as mentor, savant and collaborative forward thinker. Clarke was a polymath in mid- to late-nineteenth century Australian science and his careful retention of a vast colonial, intercolonial and international correspondence conducted from 1840 to 1876 illuminated his unique part.[8]

For the first seven years of the Royal Society, Clarke emerged as the thread on which many matters hung. As his sometime fellow Vice-President, Professor John Smith, saw it, "he was a centre around which all facts and discoveries were sure to group themselves" (Moyal, 1976, p. 57). Challenges were abundant; membership fees proved tardy; there was the need over several years for a permanent home for the Society and for a growing Library. There was also need for a wider than local emphasis, and Clarke, as an Honorary member himself of several overseas societies, early advocated extending reciprocity to other societies and offering Honorary Fellowships to reputed scientists in the Colonies and overseas. Centrally, a government stipend was urgently required to support and enhance the publications of a society which, in Clarke's words, "was performing a very important service to the community" (Clarke, 1876, pp 3-4).

In one arena, the press, the early Royal Society was singularly well supported. Proprietor John Fairfax was a member of the Society from its foundation and the practice of *The Sydney Morning Herald* in giving prominent place in its front pages to the Annual Addresses and extracts of papers from the Society's meetings the following day, in addition to its sustained scientific journalism, offered a strong and continuing image of public science. As Clarke early told Richard Owen, the newspaper "was the scientific journal of the Colony" (Moyal, 1976, p 10). Overall there was Societal growth: 116 members were reported in 1873–4, 155 in 1875, and 170 in 1876 (Clarke, 1875, p 6). As membership grew, other proposals envisaged a division into Subsections that would encourage greater concourse among specialists in different disciplinary arena. "When these separate parts are brought together," said Clarke, "all of them assist towards completion of the whole object" (Clarke, 1876, p 7). Enunciated by Clarke, these ideas were swiftly taken up and acted upon by the young Archibald Liversidge, who arrived as Reader in Geology and Assistant in the Laboratory at the University in 1872 in succession to Thomson, and joined the Society's Council in 1873. As Liversidge's biographer recounts, "Clarke had set the Society on its course of reconstruction in July 1867, he had inspired Russell and Liversidge to action in May 1875; now it was Clarke who carried the tablets from the mountain" (MacLeod, p 162). Acting in concert as Honorary Secretaries, Liversidge and Russell shouldered the Society's practical needs of finally securing some government funding to create a permanent premise, editing and adding scientific illustration to the *Transactions* and *Journal,* encouraging public science through well attended `conversationes', and steering the formation of Sections.

Clarke gave his final Anniversary Address to the Society on 1 May 1876. As the Society's shaper, he had stood essentially on the cusp between amateur and independent engagement with science and its increasing professionalization. With gathering pleasure, he saw that there had been consider-

[8] W. B. Clarke was one of the few scientists in the Colony who preserved his personal correspondence for posterity.

able progress in the Society and that the first two elected Honorary Fellows, James Hector from New Zealand and Professor de Koninck from Belgium, would recognise that they had become members of a society that was both "active and vigorous". It was a society "which had already contributed much useful information". It was not Promethean science. His central theme remained a constant. "Our true position", he reminded his audience, "is that of pioneers, sowers, foundation layers; and in that respect we have assuredly an honourable occupation… As such I have aspired to take a part … sometimes scattering a seed for thought here and there — and sometimes adding a pebble to what hereafter will, I hope, see itself surmounted by a superstructure of enduring reputation, when you and I will have long passed beyond the heats of controversy... Let us do what we can to serve honestly our day and generation" (Clarke, 1876, pp 32-3).

The Council viewed his contribution in larger terms and in 1875 commissioned Giulio Anivitti, an Italian artist recently appointed instructor in painting and drawing at the new Art Training School in Sydney, to paint Clarke's portrait. Decked in a cassock with a foreground of a globe and a substantial book, Clarke hoped that his portrait "might look down upon a flourishing Association of men". A greater recognition, however, was to come. On 1 June 1786 the Rev. W. B. Clarke, after a long and fertile scientific life, was elected Fellow of the Royal Society of London, his nomination proposed by four notable Fellows, Charles Darwin, William Stanley Jevons, Robert Lowe (former N.S.W. lawyer and politician and from 1868-73 Gladstone's Chancellor of the Exchequer), and James Hector. "The Council," wrote the Society's Secretary enthusiastically, "fully acknowledges your claims, and both Hooker and Huxley were warm in your favour, so that you came in, it may be said, triumphantly" (Moyal, 1976, pp 56, 65). Jevons, well known to Clarke when serving as assayer at the Mint, sent words to praise him. "You have founded the geology of a new continent," he graciously wrote early in November 1876, "and I might also say founded a Royal Society of your own" (Moyal, 1976, p 1147).

It fell to H. C. Russell as a new Vice-President in May 1877 to sum up the progress achieved by the Society since its foundation. "Allow me to congratulate you upon our flourishing condition," he declared. "With 132 members added to our number during the year, seven working sections, 1000 books added to our library, and friendly relations established with no less than 107 kindred societies scattered over all parts of the world" and "a fair prospect of help from a liberal government to carry out our purposes … we have good reason to congratulate ourselves" (Russell, 1877, pp 1–2).

Clarke, still actively engaged with his geological affairs, died on 16 June 1878. The Clarke Medal awarded for meritorious contributions to the natural sciences, (defined subsequently in geology, biology and zoology presented in alternate years) was dated from 1878. It marked the first scientific Medal awarded in Australia. An enduring legacy from the Society's foundation, a hundred and thirty-eight Clarke Medals have been awarded to date to distinguished leaders in their fields.[9]

[9] Attuned to his 'Association of men', Clarke would doubtless be surprised, yet perhaps gladly, that four Clarke Medals have been won by women in geology, and six in the botanical and biological sciences.

2017

One hundred and fifty years have elapsed since the founding of the Royal Society of New South Wales, which recent president, Dr Donald Hector, has claimed as "the leading learned institution of its type in Australia and in the Southern Hemisphere." For well over a century [he suggests], it was the leading learned institution in N.S.W. and, arguably, in Australia." (Hector, 2014, p 1). Functioning across decades Societies such as this have all experienced varied epochs of progress, zenith, and change (Branagan, 1972). Currently, however, Dr Hector as President from 2012–16, has become the torch bearer in a movement to effect a "renaissance" in the Royal Society to meet a new and increasingly complex environment for science and its community and "to re-establish the Society as a leader in the intellectual life of N.S.W. and of the country" (Hector, 2016, p 5).

Hector's motive, and that of his Council, springs from the perception that the Society's intellectual contribution has suffered a dilution of influence over recent decades arising from factors that include the advent of the four learned academies, increasing specialization in the scientific disciplines and in their publications, and a diminishment of communication across the disciplines. Moreover, while in its founding days, the Society of 1867 had before it "a new heaven for Astronomy and a new earth for geology", in the 21st century it has come to face a force of complex socio-techno-economic problems that are transdisciplinary, national and global in their crucial challenge.

Is there an answer? Focusing on mankind's "remarkable capacity for intellectualizing problems and solving them in the abstract" (Hector, 2016, p 6), Hector early put the case that the Society could play a special role in bringing much greater insights into previously unassailable problems. The Royal Society, he argued, "is uniquely placed to provide leadership in this type of complex analysis". At a first level, the Society can provide "a forum where like-minded people can gather and understand what is happening in other disciplines" (Hector, 2014, pp 1–2). He also underlined, that the "wisdom of the founders in defining such a broad remit of human knowledge — science, art, literature and philosophy — was truly prescient". But the current environment called for major change. Solutions, he advised, will not be found in science and technology alone. For impact, "we need more writers, architects, sociologists, musicians and historians" (Hector, 2016, p 15). Only then will we be able to engage with the community: "we can harness both intuitive and rational thought to bring great creativity", he said. It marked a clarion call.

By 2012 the Council had already stirred a sense of outreach and collective action. The Society was engaged in a range of awards and special named lectures (the Dirac Lecture in the physical sciences is one). In February 2013 the Society held its first annual Four Societies Forum with the Nuclear Engineering Panel of the Sydney Branch of the Institution of Engineers, Australia, and the Australian Institute of Energy. In a key Council initiative, several highly eminent members of the science community already linked to the Society were elevated as `Distinguished Fellows': Nobel Laureates, Professors Peter Doherty and Brian Schmidt, Sydney-born, former UK Chief Scientist, Lord May, Emeritus Professors Jill Trewhella and Eugenie Lumbers, Professor Michael Archer, and the Hon. Barry Jones, unique as an elected Fellow of all four learned Societies

(Hector, 2014, p 2). In December 2013, a further Council decision was taken to extend the knowledge base of the Society through the election as special members of a number of highly accomplished leaders across fields of knowledge drawn from the professoriate of the universities in the State of New South Wales. The Awards Advisory Panel, composed of the Deans of Science and the Deans of Engineering, chaired by Professor Mary O'Kane, Chief Scientist and Engineer of New South Wales, selected some twenty-one new members — the "FRSN" — for formal election in May 2014.

Other ventures flourished. The first Forum of the Society with the four learned Academies was held at Government House, Sydney, in September 2015 on 'The Future of Work'[10]. Introduced by the Governor, General David Hurley, it brought a broad range of academics and business leaders to bear on one of the big national and social issues, "a futuristic look at the technological, social and cultural change expected over the next 30 years" (RSNSW Annual Report 2014) expressing in the Governor's words "the Royal Society's defining purpose of rigour in challenging received opinion and dominant authority through its motto, *omnia quærite*, question everything". A second Joint Forum of the Society and the four Academies, held at Government House in 2016, titled 'Society as a Complex System: Implications for Science, Practice and Policy', spanned a wide scientific and political spectrum and brought diverse minds to bear. The papers from both Forums are published in the Society's *Journal & Proceedings*. This in-house resource has also been reinvigorated to include key invited lectures and articles solicited for special issues, and others based on personal historical background. Extending new membership has brought needed finances to the Society while its core goal of "renaissance" is expressed in its wide intellectual interaction, consultation, multidisciplinary narratives, and in the stimulus of personal interconnections. Embracing community, the Society's Annual Dinners gather participants in a linked reflection of the 'conversationes'.

Special invited lectures throw critical light on key often "wicked" problems. Speaking at the Awards Dinner on 7 May 2014, savant and one-time politician, Barry Jones contended that "the quality of public debate on scientific issues had been trivialised, even infantilised". "Despite Australia's large number of graduates (more than 4 million)," he said, "our 38 universities and intellectual class generally have very limited political leverage and appear reluctant to offend government or business by telling them what they do not want to hear… In a democratic society such as Australia, evidence is challenged by opinion and by vested and self-interest. Australia has no dedicated Minster for Science with direct ownership/involvement in promoting scientific disciplines." In an era of super-specialisation, he suggests "many scientists are reluctant to engage in debate, even where their discipline has significant intersectoral connections" (Jones, 2014).

A widely disseminated lecture by Distinguished Fellow, Professor Brian Schmidt, on 'Evidence and Expertise in a post-truth world,' invites us to inspect the tenuousness of our human future. He sees "a post-truth world" itself as a threat to our survival and one that, unless dealt with quickly, threatens us severely. Our planet, he reminds us, emerged 3.7 billion years ago "a small grain of sand" in the universe, but a grain we need to

[10] See https://royalsoc.org.au/council-members-section/240-jprocrsnsw-vol-148-2

preserve. There are 7.4 billion people now on Planet Earth, and an increase of one hundred million every year. Using energy, water, land and pollution we have a difficult challenge on our hands: that "we, humanity, have to fit on Earth," as Schmidt says. In this, "evidence and expertise" are critical. Numerate, deeply expert in the history of the universe, Schmidt contends that "we will be a bunch of rabbits around a waterhole" if we take wrong or inconsequential action. "It is only by being human," he maintains, and, by using decisions to share Planet Earth in learning to reduce our collective population and distribute the planet's finite resources, "that we will have a path that will enable us to save ourselves". (Schmidt, 2017). Or as Bill Bryson (2010) writes more simply in *Seeing Further: The Story of Science and the Royal Society*, "If we have an earth worth living on a hundred years from now, the Royal Society [of London] will be one of the organizations our grandchildren will wish to thank" (p 13).

On a smaller canvas in its transformative processes, the Royal Society of New South Wales has much to share with, and learn from, this ancient Society. With its seven journals, its endless stream of papers, its communication through lectures, its transdisciplinary principles, its manifold committees, its many awards and prizes, its contribution to changing legislation, it exemplifies many concepts and trends that the N.S.W. Society endorses. Articulate for many years in the climate change debate, work-shopping and despatching a steady flow of communications on policy to government and the media, it also provides public information to the lay reader on energy policy and global warming. By repute, the Royal Society of London provides "a vibrant showcase of science". It also acts as "the conscience of a nation" (Bryson, p. 13).

In a richly engaged period for the Royal Society of New South Wales, large and unpredictable questions lie ahead. Martin Rees (2010, p. 485) offers a fitting frame for us all in his 'Conclusion: Looking Fifty Years Ahead' in Bryson's *Seeing Further*. "Wise choices will require the idealistic and effective efforts of natural scientists, environmentalists, social scientists and humanists — aided by the insights that twenty-first century science will surely bring."

From 1867 to 2017 such recommendations have the ring of truth.

Acknowledgments

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Dr Ann Moyal, historian of Australian science and technology, is the recipient of the Royal Society's Inaugural Medal for the History and Philosophy of Science, 2015.

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Thesis abstract

Role of Progesterone Receptor Membrane Component 1 (PGRMC1) in cancer cell biology

Partho Adhikary

Abstract of a thesis for a Doctorate of Philosophy submitted to Charles Sturt University, Wagga Wagga, Australia

Progesterone Receptor Membrane Component 1 (PGRMC1) is a 22 kDa Cytochrome b5 related haem-binding protein. PGRMC1 is an evolutionarily conserved protein. It is involved in maintaining various cellular processes such as damage resistance, lipid and drug metabolism, apoptosis and cell proliferation. PGRMC1 is over expressed in multiple types of cancer. It plays an important role in cancer by regulating tumour growth and cell differentiation. A previous proteomics study on human breast cancer tissue found that PGRMC1 was phosphorylated. Three different isoforms of PGRMC1 were identified and phosphatase treatment revealed those isoforms were differentially phosphorylated. PGRMC1 protein contains putative Serine and Tyrosine phosphorylation sites and has binding sites for Src homology 2 (SH2) and SH3 domain containing proteins. In this thesis, I investigated the role of phosphorylated PGRMC1 in cancer cell biology and tumourigenesis. I generated mutant stable cell lines by removing putative phosphorylation sites at Serine and Tyrosine residues of PGRMC1. Removal of phosphorylation sites in the Mia PaCa-2 pancreatic cancer cell line, affected the cell biology profoundly. It induced changes in cellular proteome and signalling pathways. It changed cell morphology and migration patterns, induced mesenchymal to amoeboid transition. It affected glucose uptake and lactate production. Overexpression of wild type PGRMC1 showed more cancer relevant phenotype. Depletion of PGRMC1 by RNA interference and removal of Serine phosphorylation sites impaired MDA-MB-231 breast cancer cell's metastatic growth in a mouse xenograft model. Overexpression of PGRMC1 increased breast cancer bone metastases and induced osteolytic bone damage. Taken together, these results suggest that PGRMC1 is involved in tumourigenesis and a potential target for cancer therapeutics.

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Thesis abstract

Adventure therapy: treatment effectiveness and applications with Australian youth

Daniel Bowen

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Canberra, Bruce, Australia

Adventure therapy involves use of small groups, nature-contact, adventure activities, and therapeutic processes to create opportunities for psychological change in participants, usually with the purpose of supporting an individual (or family) to move towards greater health and well-being. Adventure therapy programs involve diverse target groups, settings, program models and aims; yet too little is understood about their characteristics and efficacy. This thesis, including published works, assists in improving the health and well-being of Australian youth by providing up-to-date information, and consolidating and advancing understanding of the therapeutic uses and treatment effectiveness of adventure therapy. Further, by evaluating two specific therapeutic adventure-based interventions for youth, this thesis provides valuable insight about the current utility and therapeutic outcomes of adventure therapy programs in Australia.

This thesis includes four studies reported in four papers, each of which contributes to its overall aims. Study 1 examines the efficacy of adventure therapy programs internationally through a meta-analysis of outcomes and moderators. Study 2 provides an up-to-date description of outdoor adventure interventions for youth in Australia based on a national survey of program managers and leaders. Study 3 examines the efficacy of the Wilderness Adventure Therapy®[1] (WAT) model of clinical treatment for Australian youth, while Study 4 examines the efficacy of the Queensland Police-Citizens Youth Welfare Association Bornhoffen Catalyst program for Australian youth-at-risk.

Meta-analytic results from Study 1 confirmed that adventure therapy programs are moderately effective (.47) in facilitating positive short-term change in psychological, behavioural, emotional, and interpersonal domains and that these changes appear to be maintained in the longer-term. Such magnitude of benefit is comparable to the majority of efficacious treatments for patients across the age span reported in the literature. As the most comprehensive and robust meta-analysis of adventure therapy studies to date, the findings from Study 1 can be recommended for use in benchmarking and monitoring program effectiveness. Results from Study 2 indicated considerable breadth, depth, diversity and differences in the organisation, program, staff, and participant characteristics of outdoor adventure interventions in Australia. The main outcomes of outdoor adventure interventions, as perceived by staff, were recreation, and personal and social development. Surveyed staff believed that the

[1] Wilderness Adventure Therapy® is a registered trademark in Australia and New Zealand.

majority of participants obtained significant long-lasting benefits. Findings from Studies 3 and 4 suggest some cautious promise that two Australian adventure therapy programs (WAT and the Catalyst program) each offer a viable alternative to traditional psychotherapeutic approaches through prevention and intervention programs for youth-at-risk.

Overall, the findings of this thesis confirm that adventure therapy has the potential to play important roles in improving the health and well-being of Australian youth. While adventure therapy is not a panacea, these findings indicate that it is useful in a wide range of settings and for a broad spectrum of clients. Thus, findings from this thesis strongly support the assertion that adventure therapy should be in the suite of therapeutic interventions that operate in diverse service settings across Australia.

Future research could build on Study 2 by conducting a dedicated survey of adventure therapy programs in Australia. In addition, research utilising a comparison or wait-list control group, multiple sources of data, and a larger sample, could help to qualify and extend findings of Studies 3 and 4. Overall, despite the promising findings, more rigorous research evaluations of adventure therapy programs (e.g., quasi/experimental, case study, observational, mixed method, and longitudinal design) are needed to strengthen the reliability, validity, and usability of adventure therapy research.

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Thesis abstract

Delinquency and problem drinking among Australian youth: a common cause psychosocial control perspective

Angela Curcio

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Canberra, ACT, Australia

Delinquency and problem drinking are two commonly occurring risk-taking behaviours among youth. Relative to delinquency, far less research has focused on an integrated theoretical framework of problem drinking that considers both psychological and social factors. Based on common cause conceptualisations of youth problem behaviours, the overarching aim of the current thesis was to examine whether an existing psychosocial control theory of adolescent delinquency could be modified and extended to explain both delinquency and problem drinking behaviours among non-clinical samples of adolescents and young adults in the contemporary Australian society. In order to achieve this overarching aim, this research program employed a sequential mixed methods design that consisted of five phases.

While prevalent youth problem behaviours often co-occur, risk factors underlying delinquency and problem drinking are not usually considered together. Thus, Phase I involved a systematic review of the literature to explore whether delinquency and problem drinking share psychosocial risk factors. Providing support for a common conceptual model, shared risk factors were found and broadly encompassed within Mak's (1990) psychosocial control theory of adolescent delinquency, with the exception of sensation seeking and peer risk-taking behaviours.

Owing to a paucity of qualitative research incorporating stakeholders' views pertaining to adolescent delinquency and problem drinking, Phase II comprised a qualitative study to determine risk factors for delinquency and problem drinking from the phenomenological perspectives of adolescents and relevant stakeholders. Risk factors tended to be congruent with the proposed revisions to psychosocial control theory as identified in Phase 1.

In order to examine risk factors underpinning delinquency and problem drinking, current and reliable instruments that accurately reflect the incidence of these behaviours among young Australians in the general population are required. Therefore, the objective of Phase III was to update an Australian measure of adolescent delinquency to ensure representation of prevalent delinquent activities and consistency with the current youth culture. The revised instrument was subsequently utilised to examine the concurrence between adolescent drinking with domains of delinquent offending.

Although the majority of research pertaining to psychosocial control theory has focused on adolescent samples, there is evidence to suggest that the extent of problem drinking is particularly concerning among

young adults in Australia. Therefore, phases IV and V tested, and found broad support for, the revised psychosocial control model to explain delinquency and problem drinking respectively, spanning from early adolescence to emerging young adulthood.

This thesis including published works, makes an original contribution to the field by using a systematic literature review, qualitative stakeholder enquiries, and empirical quantitative research to identify shared risk factors for delinquency and problem drinking, and subsequently tested, and provided broad support for, an integrated psychosocial control framework of delinquency and problem drinking along a trajectory from early adolescence to young adulthood. This research program additionally generated five self-report measures with sound psychometric properties. This thesis has highlighted the role of risk-taking peers as a potential mediator between conventional social control agents with delinquency and problem drinking, as well as establishing conceptual and empirical differences between impulsivity and sensation seeking as risk factors for youth delinquency and problem drinking.

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Thesis abstract

A philosophical-empirical interrogation of infant participation in research

Sheena Elwick

Abstract of a thesis for a Doctorate of Philosophy submitted to Charles Sturt University, Wagga Wagga, Australia

This thesis is about a philosophical-empirical interrogation of infant participation in research. It reports on a doctoral study that brought together philosophy from diverse backgrounds, empirical data, and an interrogation of the concept of infant participation. The study was located in an Australian Research Council Linkage project that endeavoured to enable infants to enact their participatory rights in research concerning their lives in early childhood education and care (ECEC) environments.

Moves towards employing participatory research approaches with infants are influenced by several discourses including discourses of children's rights and discourses related to participatory research with older children. Notably, Article 12 in the *United Nations Convention on the Rights of the Child* is often presented by researchers as entitling infants the right to participate in research concerning their lives. Language, methodological foci, and methods used in participatory research with older children are also frequently presented as appropriate. The rhetoric of infant participation has, therefore, mostly been put into practice as 'listening' to and reporting on infants' experiences and 'perspectives' via observation of their expressions and behaviours. Once ascertained, those experiences and 'perspectives' are reported on, by and large, in the form of second-hand narratives, and excerpts of video-recordings, or case-studies, that are subsequently analysed through various theoretical and conceptual lenses. Whether or not such research achieves what it claims to achieve in regards to enabling infants to efficaciously enact their human rights, and particularly their participatory rights, is generally left unquestioned. This thesis problematises and responds to that absence of questioning and, in the process, provides an in-depth example of a philosophical-empirical interrogation of infant participation in research.

The aim of the study was to negotiate ethical and participatory relations with the infants involved in the study, from within the complexities of the moments that we shared. To that end, I shifted my attention away from researching and writing about infants' expressions and behaviours (infants' bodies, so to speak) towards researching and writing about my own bodily responses as I opened onto a world that included infants (and others) in specific times and spaces; and the ethical reflexivity and questions that emerged. I also drew on moments shared with six infants (aged birth to eighteen months) in three Family Day Care homes, and a diverse range of scholarly sources that

included Merleau-Ponty's philosophy as a common thread, to interrogate the questions and uncertainties that emerged.

The findings of the study suggest that although attention has been given to responding to infants' rights as outlined in Article 12, and the value of that response is recognised, much less attention has been directed towards critiquing and evaluating the effectiveness of those responses in practice. This has, perhaps, resulted in a gap between the rhetoric of infant participation and how infant participation is negotiated between particular researchers and infants in specific times and spaces. The findings of the study also revealed that it was through my own carnal responsivity to infants' presence, during my encounters with infants, that they were able to displace my experience of self, provoke ethical reflexivity and provide unexpected possibilities for moving forward together towards a shared future. Engaging with that experience of displacement and the questions provoked is essential to establishing any emancipatory discourse concerning infants.

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Thesis abstract

Determinants of the Islamic revival and its political implications

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Abstract of a thesis for a Doctorate of Philosophy submitted to University of New South Wales, Sydney, Australia

Culture and religion have only gained interests among economists in the last couple of decades. In fact, Adam Smith[1] was the first scholar to establish a link between religion and economics. Yet, the link may at first not be obvious. So the natural question to ask is how do religion and economics interact? There are many ways through which economics, religion and politics can be associated. Values and beliefs stemming from religion may affect individuals' preferences and thus their economic, social and political behaviours. Likewise, engaging and/or supporting religious political activism and parties may emanate from a rational choice. This dissertation contributes to the emerging literature of economics of religion focusing on Islam. It does so by providing empirical insights seeking to enrich understanding of this religion in ways that intersect political sciences and economics. First, it reveals that economic factors as redistributive considerations are crucial in explaining support for political Islam. Second, it shows that feelings of frustration are a plausible source of the revival of the Islamic culture among initially religious individuals. This suggests that Islam per se does not trigger considerable social behaviours. Yet, it makes one feels closer to her/his group and further apart from other groups, thus reinforcing club-good effects. Finally, this dissertation argues that Muslims' attitudes towards women are not necessarily in the expected direction in terms of material deprivations as often portrayed in the literature. The empirical insights of this dissertation, that may challenge preconceptions attached to Islam, are the results of original field work. The first and second chapters use a representative sample of 600 Tunisians. The second and third chapters use lab-in-the-field experiments which combine both external validity of the field data and results from cautiously designed experimental games.

Render Unto Caesar: Taxes, Charity and Political Islam (joint with Gabriele Gratton and Pauline Grosjean)

In this chapter, we investigate the origin of political support for religiously affiliated parties. Using an original, nationally representative survey of 600 individuals, we show that support for Islamic parties in the first post-Arab Spring Tunisian election came from richer districts and individuals. We show that standard public finance arguments help explain this voting pattern better than other available explanations. Our model pre-

[1] Smith, Adam. 1979. *An Inquiry into the Nature and Causes of the Wealth of Nations: Books I–III*. New York: Penguin, 1776.

dicts that a voter's probability to vote for a religious party: (i) increases in income for the poorest voters, but possibly decreases in income for the richest; (ii) is greater for voters in richer districts; and (iii) increases with the voter's religiosity. Our empirical results align with our predictions and suggest that belonging to the middle class and living in a richer district together affect voting decisions more than being a religious voter. We test for other possible factors affecting voting, such as education, frustrated aspirations, or attitudes towards corruption. Finally, we document similar patterns in other key elections in the Muslim world.

Envy and the Islamic Revival: Experimental Evidence from Tunisia

In this chapter, I investigate the psychological factors at the origin of the Islamic revival, defined as the recent resurgence of Islamic culture and against previous trends of "westernization." I design and conduct a survey with an embedded lab-in-the-field experiment to test whether envy triggers popular support for the Islamic revival using a nationally representative sample of 600 Tunisians. Envious individuals who live in highly unequal environments and feel relatively poor are more likely to engage in religious and political activities. I trigger envy with a 2 × 2 design by interacting a priming video and low stakes. I find that individuals in the envy treatment donate a larger proportion of their endowment to a religious political charity, my measure of support for the Islamic revival. The effect is more pronounced among highly religious individuals but is otherwise less robust. The survey data provide consistent results with my experimental findings. Overall, the results confirm the idea that envy is a key determinant of popular support for the Islamic revival, but its effect is conditional on the individual already being highly religious.

Are Muslim Immigrants Really Different? Experimental Evidence from the Lebanese Australian Community (joint with Danielle Hayek)

In this chapter, we investigate whether Muslim immigrants in a Western destination country behave differently from their Christian counterparts towards females and the poor. We test this by conducting a Prisoner's dilemma and a Dictator game with Lebanese Australians. Lebanese Muslims and Christians are comparable in all aspects but religion. Hence, using this sample allows us to isolate the role religion plays in shaping social attitudes as we are able to remove the effects of economic institutions of country of ancestry and hold constant all other factors such as ethnolinguistic groups. We find that when compared to Christians, Muslims are significantly more cooperative with the poor and that this effect is stronger when the poor recipient is female. The effect remains even after controlling for altruism.

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Thesis abstract

Contemporary political participation: exploring the relationship between technology and politics in late modernity

Max Halupka

Abstract of a thesis for a Doctorate of Philosophy submitted to University of Canberra, Canberra, Australia

This thesis by publication analyses emerging forms of civic engagement, focusing particularly on conceptualising technology's relationship with politics. It explores three central issues within current debates on alternative forms of political participation. First, it critiques the dualism between arena and process definitions of politics, and suggests how it can be overcome (Halupka 2017). Second, it examines the division between collective and connective action movements in both theory and practice (Halupka 2015). Third, it focuses upon the impact that new technology, specifically the internet, has had on political participation (Halupka 2014). Taken together, this thesis addresses a number of significant conceptual and theoretical issues that the literature had largely ignored. Consequently, this paper looks to extend current theoretical and empirical debates, and, in this way, to move the literature in new directions.

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Thesis abstract

Sindhī multiscriptality, past and present: a sociolinguistic investigation into community acceptance

Arvind Iyengar

Abstract of a thesis for a Doctorate of Philosophy submitted to the University of New England, Armidale, Australia

This thesis falls within the field known as the sociolinguistics of writing, namely, the study of the role of written language and writing in society. It deals with the mutual relationship between the written form of a language and a community that uses the language, and how the use of written language within the community is impacted by societal changes.

The thesis focuses on Sindhī, an Indo-Aryan language native to the Sindh province of southern Pakistan, but also spoken by 1.7 million people in India. The minority Sindhī community in India is recognised as having achieved exceptional economic success and near-universal literacy. However, the community has attained literacy predominantly in languages other than Sindhī, chiefly English and Hindī. In fact, community competence in written Sindhī in India has been declining for several decades. This is attributable to the lack of economic use for the language in India, and to the fact that the language has traditionally been written in the intricate Perso-Arabic script. Consequently, community motivation to learn this script purely for reading and writing Sindhī is low. Attempts have been made to use the Devanāgarī script for the Sindhī language in India, with partial success. Of late, a community proposal for using the Latin or Roman script for the Sindhī language has emerged, claiming to bridge the script divide in the community between Perso-Arabic and Devanāgarī.

On this basis, the thesis investigates the use of scripts for the Sindhī language, both from a diachronic and synchronic perspective. It addresses the questions of how and why certain scripts were and are being used for the Sindhī language. It also explores what the Indian Sindhī community today feels about using the Roman script to read and write the Sindhī language. In doing so, the study examines the potential Roman has in improving community competence in written Sindhī, and identifies solutions that may aid Sindhī language maintenance in India.

The thesis first analyses the rich but understudied script history of the Sindhī language from the tenth century to modern times. Domains in which certain scripts were used are investigated, and definite patterns in script distribution are identified. Particular attention is paid to Perso-Arabic and Devanāgarī, which emerged as the two most widely used scripts for the language in the twentieth century. The diachronic analysis draws on archival sources as well as academic works on the Sindhī language, and brings to the fore hitherto neglected data on historical script use for the language.

The thesis then analyses present-day community opinion on the proposal to use the Roman script to read and write Sindhī. Distinct themes in community opinion are highlighted, and popular semiotic associations of Roman, Perso-Arabic and Devanāgarī are identified. The synchronic analysis is based on original fieldwork data, comprising in-depth qualitative oral interviews with members of the Indian Sindhī community (n = 50) of diverse backgrounds and ages from various geographical locations.

The findings of the historical and contemporary sociolinguistic investigation in this study challenge the simplistic view prevalent in the literature that past and present script use for the Sindhī language has been the result of either authoritarian imposition or voluntary choice. They also question the oft-asserted claim in the literature that the choice of script for a language is a reflection of its speakers' ideological affiliation. Rather, the study's findings point to more quotidian factors influencing historical and contemporary script use for Sindhī, including socio-economic need and situationally-determined appropriateness. The study's findings also indicate that community members consider oral competence in the Sindhī language to be more important than written competence in it. Finally, from a pedagogical point of view, both Devanāgarī and Roman are shown to have distinct advantages for beginner readers in Sindhī. The thesis thus makes key contributions not just to the existing body of knowledge on the Sindhī language, but also to the fledgling field of inquiry that is the sociolinguistics of writing.

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Thesis abstract

Phosphorus remobilisation during grain filling in rice

Kwanho Jeong

Abstract of a thesis for a Doctorate of Philosophy submitted to Southern Cross University

Phosphorus (P) is applied to crops to ensure high yields but adds to costs and contributes to water eutrophication. Most P in cereals is in harvested grain removed from fields. Improving plant P recycling and/or reducing the P in grains may overcome this; however, the physiology and molecular mechanisms of P remobilisation from vegetative tissues to developing grains must be better understood.

The pattern of P accumulation in developing rice (*Oryza sativa* L. *ssp. indica* cv. IR64) grains and P remobilisation from flag leaves were investigated during grain filling. Transcriptome (RNA-seq) analysis was undertaken at two time points, six days after anthesis (DAA) when flag leaf P content was maximal, and 15 DAA when flag leaf P content had declined due to P remobilisation to developing grains. Three P-starvation response (PSR) genes (*OsPAP3*, *OsPAP9b* and *OsPAP10a*) and three genes not previously implicated in the P-starvation response (*OsPAP26*, *SPX-MFS1* and *SPX-MFS2*) had expression profiles consistent with a role in P remobilisation. Metabolic pathway analysis suggested phospholipids may be degraded and replaced by other lipids, liberating P for export to developing grains.

The effect of P withdrawal from nutrient solution during grain filling on biomass accumulation, yield, flag leaf photosynthesis and remobilisation of P from leaf P fractions was investigated. Phosphorus withdrawal at anthesis or 8 DAA impaired photosynthesis by 16 DAA, presumably due to competition for P between vegetative tissues and developing grains. Withdrawal of P at anthesis led to premature mobilisation of inorganic P (Pi) from flag leaves at 8 DAA, most likely vacuolar Pi that met the P demands of developing grain while ensuring sufficient P was available for metabolic activities. The lipid P fraction appeared to be the first P fraction mobilised at 8 DAA when P was withdrawn at anthesis, presumably because reserves of vacuole Pi were insufficient. Early remobilisation of lipid-P suggested phospholipids were replaced by other lipids to conserve P, although further lipidomics studies are required to confirm this.

RNA-seq analysis of flag leaves under P-limited conditions during grain filling identified genes which may play a role in P remobilisation during grain filling. The response to P withdrawal was clearly distinct between early (8 DAA) and the later (16 DAA) stages of grain filling. Upregulated expression of genes involved in photosynthesis occurred at 8 DAA while at 16 DAA withdrawal of P induced genes involved in the degradation of polysaccharides to monosaccharides.

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Thesis abstract

Outsourcing responsibility. Towards a transformative politics of domestic work

Ulrike Prattes

Abstract of a thesis for a Doctorate of Philosophy submitted to the Australian Catholic University, North Sydney, Australia

In this doctoral thesis, I start from the body of feminist scholarship on "outsourcing" domestic and care work in the global North. I maintain that this debate has importantly highlighted the interactions of gender with class, race, and ethnicity. In its almost exclusive focus on differently situated women, however, the debate tends to reproduce the organization and performance of reproductive work as a "woman's issue," simultaneously shrouding men's positions therein. Via an in-depth empirical study, I conducted with five domestic work outsourcing, opposite-sex couples in Vienna, Austria, I seek to bring to the fore the affective relations and corporeal practices of responsiveness and non-responsiveness between the outsourcing partners, and their positioning vis-à-vis migrant domestic workers. Using a relational concept of responsibility, I argue that responsiveness to human interconnectedness is required for responsible practices to emerge. I critique the notion of the supposedly "self-sufficient" autonomous individual, and draw on feminist care ethics, to highlight the existing relationality and interdependence among the various actors. I position my project against the positivist paradigm and bring empirical and theoretical material into a conversation at eye level.

First, I trace the reproduction and maintenance of unjust structures within the field of outsourcing in concrete, everyday, social interaction in order to emphasize their social nature and changeability. I strive for a systemic portrayal of non-responsive practices as shaped by an epistemology of ignorance, rather than accidental "failures," and thus critique asymmetrical structures, not individual "character flaws." Second, I want to identify existing potentials for transformation in regards to the structurally vulnerable position of migrant domestic workers. I highlight potentials for transformation towards social justice that are there and should be amplified. These consist of feelings of guilt, which I here read as affective "spill-over" that cannot be contained within the narrative of autonomous, independent individuals on the one hand; and on the other hand, practices of responsiveness, and the potential for creative embodied, (affective and relational) performances.

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Thesis abstract

Localising the Global Eco-Schools™ Program in South Africa: a postcolonial analysis

Elizabeth Ryan

Abstract of a thesis for a Doctorate of Philosophy submitted to Southern Cross University

Environmental educators are exhorted to 'Think Global and Act Local'. This popular refrain encourages environmental educators to consider the interface between the universal and the particular. It also highlights the ways global environmental education programs such as the Foundation for Environmental Education's (FEE) Green Flag Eco-Schools Program can shape the pedagogy and practice of environmental educators in localized settings around the world. Originally a Danish initiative designed for a European context, the Eco-School Program is now the most widely adopted environmental education program in the world, deployed in over 64 countries. As such it has the capacity to significantly influence environmental education pedagogy and practice internationally, yet little is known about its effect.

My research explores the influence of Eco-Schools on the ways that teachers from non-Western contexts understand themselves and their work. Specifically, I am interested in understanding the extent to which Eco-Schools, as exemplars of a global environmental education program, impose particular discourses, visions or imaginaries of what it means to be an environmental educator on teachers in Southern contexts. Through a case study of the implementation of FEE Eco-Schools in South Africa, I explore the ways in which the program shapes what counts as environmental education knowledge, what pedagogies are deemed appropriate, and what kinds of student actions are encouraged.

The key research questions I address are:

1. How are Eco-Schools teachers imagined through global and local discourses?
2. How has the South African host organisation (WESSA) interpreted Eco-Schools discourses; and what are the mechanisms through which they subject Eco-Schools teachers to these discourses?
3. How do South African Eco-Schools teachers subject themselves to, and resist, such discourses?

A postcolonial lens is employed to illuminate the everyday effects of power on teachers' perceptions of themselves and their work. Postcolonial concepts offer an innovative way of investigating teacher identity and self-perceptions of capacity and agency in environmental education because they emphasise the powerful colonising effects of discourse as well as the possibility of agency through discursive disruption. My research provides a telling case study of Eco-School teachers in South Africa and how they are both subject to and subject themselves to different teacher identities made available through Eco-Schooling discourses. Through the methodology of postcolonial discourse analysis, I draw upon a range of global Eco-Schooling policies and curriculum resources as well as interviews with South African Eco-School coordinators and teachers to explore how Eco-Schooling identities are negotiated across global and local discursive fields in South Africa. My research shows how Eco-School teachers are both taking up and resisting dominant discourses available in these global and local arenas, creating new hybrid identities that offer spaces for teacher agency.

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Proceedings of the Royal Society of New South Wales
The 2017 programme of events – Sydney

Held at the Union, Universities and Schools Club, 25 Bent St, Sydney unless otherwise stated.

Wed 1 Feb	1250th Ordinary Meeting RSNSW Scholarship winners	Yik Lung (Jeremy) Chan, University of Technology Sydney Andrew Ritchie, University of Sydney Isobel Ronai, University of Sydney	Effects of maternal cigarette smoke exposure on brain health in offspring New ways of modelling the ancient past to understand evolution Anarchy in the honey bee colony: the genetic basis of worker sterility
Thu 23 Feb	The Four Societies Lecture	Rear Admiral, The Honourable Kevin Scarce AC CSC RAN (ret'd.)	South Australia: a nuclear State in a global solution
	Held in conjunction with the Nuclear Engineering Panel of the Sydney Branch of Engineers Australia, the Australian Nuclear Association and the Australian Institute of Energy. Held at Hamilton and Parkes Rooms, Level 47, MLC Centre, King and Castlereagh St.		
Wed 1 Mar	1241st Ordinary Meeting	Richard Ferguson FRGS Executive Director, Craft Australia	Creative minds: Artistic and scientific endeavour on polar expeditions 1851 to 1951
Wed 5 April	1242nd Ordinary Meeting and 150th Annual General Meeting	Dr Greg Organ Senior Sensory Specialist, Lion Company	The science of beer
Wed 3 May	Annual Dinner: Distinguished Fellow's Lecture and presentation of the Society's 2016 awards	Guests of honour: The Society's Vice-Regal Patron, His Excellency General The Honourable David Hurley AC DSC (Ret'd), Governor of New South Wales and Em. Professor Peter Baume AC DistFRSN	Don't blame the unemployed

Thu 11 May	Liversidge Lecture	Scientia Professor Justin Gooding, UNSW	Sensing our world: From glucose sensors to counting single molecules and cells
	Held in conjunction with Royal Australian Chemistry Institute. Held at Tyree Room and Balcony, John Niland Scientia Building, UNSW		
Wed 7 June	1253rd Ordinary Meeting	Professor Madeleine Beekman, University of Sydney	Are you smarter than a slime mould?
Wed 5 July	1254th Ordinary Meeting	Professor Andrea Morella	Understanding Quantum Theory
Wed 2 Aug	1255th Ordinary Meeting	Professor Ann Williamson UNSW	Self-Driving Cars: Will they help?
Tu 1 Aug	ANSTO, AIP, RACI, RSNSW	Round Table Discussion with Em Prof Heinreich Hora, Grahame Campbell, Dr Richard Garrett	The Future of Fusion
	Held in conjunction with the Australian Institute of Physics, the Australian Nuclear Science and Technology Organisation, the Royal Australian Chemical Institute and RSNSW. Held at the Discovery Centre, ANSTO, Lucas Heights		
	Sydney Science Festival lunchtime science talks		
Fri 11 Aug	Sydney Science Festival	Professor John Murray, UNSW	Smoking and lung cancer: How are we doing?
Mo 14 Aug	Sydney Science Festival	Dr Kathleen Riley, Writer, classical scholar and theatre historian	Fred Astaire and the Science of Spontaneity
Tu 15 Aug	Sydney Science Festival	Professor Leslie Burnett, Garvan Institute of Medical Research	Personalised medicine – healthcare in the 21st century
Thu 17 Aug	Sydney Science Festival	Em Professor D Brynn Hibbert, UNSW, President RSNSW	Scientific and not-so-scientific fraud: crooks, cranks and charlatans

Tu 29 Aug	Poggendorff lecture	Associate Professor Andrew Robson, University of New England	Applied remote sensing applications for Australian agricultural and horticultural industries
	Held at Mitchell Theatre, Level 1, Sydney Mechanics' School of Arts, 280 Pitt St., Sydney		
Mo 4 Sep	RSNSW/SMSA Enlightenment Series	Susannah Fullerton, Author, lecturer and literary tour leader	Lecture 1: Samuel Pepys, His Library and the Enlightenment
	RSNSW/SMSA Joint Lecture Series: Is the Enlightenment dead? Held at Mitchell Theatre, Level 1, Sydney Mechanics' School of Arts, 280 Pitt St., Sydney		
Wed 6 Sep	1256th Ordinary Meeting	Dr Helen Mitchell, Conservatorium of Music	Multisensory music: listening by ear and eye?
Wed 4 Oct	1257th Ordinary Meeting	Professor Pip Pattison AO, Deputy Vice Chancellor, University of Sydney	The science of social networks
Mo 6 Nov	2016 Dirac Lecture	Professor Boris Altshuber Columbia University	Dark Matter in the Universe
	Held at Ritchie Theatre, John Niland Scientia Building, UNSW		
Mo 6 Nov	RSNSW/SMSA Enlightenment Series	Professor Robert Clancy AM	The freedom to use one's own intelligence: the Enlightenment and the growth of the Australian nation
	RSNSW/SMSA Joint Lecture Series: Is the Enlightenment dead? Held at Mitchell Theatre, Level 1, Sydney Mechanics' School of Arts, 280 Pitt St., Sydney		
Wed 1 Nov	1258th Ordinary Meeting	Pamela Griffith, Artist, designer, master printer and author	Women artists: barriers and frustrations
Tue 29 Nov	RSNSW and Four Academies Forum	Government House, Sydney; hosted by his Excellency General The Honourable David Hurley AC DSC (Ret'd) Governor of NSW and Patron of the Royal Society of NSW at Government House	The future of rationality in a post-truth world
	Held in cooperation with the Australian Academy of Science, the Australian Academy of Technological Sciences and Engineering, the Australian Academy of the Humanities and the Academy of Social Sciences in Australia.		
Wed 6 Dec	1259th Ordinary Meeting	Royal Society of NSW 2017 Jak Kelly Award: Moritz Merklein, University of Sydney	How to store light: an optical memory based on sound waves

The 2017 programme of events — Southern Highlands

Held at the Performing Arts Centre, Chevalier College, Bowral. Venue from October 2017: Mittagong RSL, 1st Floor, Joadja/Nattai Rooms.

Thu 16 Feb 2017	Prof Adam Guastella Brain & Mind Research Institute	Autism and ASD (Autism Spectrum Disorder)
Thu 16 Mar	Dr Barbara Briggs Royal Botanic Gardens	Two hundred years of the Royal Botanic Garden Sydney, Australia's oldest continuing scientific institution.
Thu 20 Apr	Dr Michael Kennedy Consultant Physician and Clinical Pharmacologist, St Vincent's Hospital	Post mortem drug studies : What happens to drugs after death
Thu 18 May	Prof Gregg Suaning Professor of Biomedical Engineering, University of NSW	The Bionic Eye "... to do for vision what the Cochlear implant has done for hearing"
Thu 15 June	Dr Michael Birrell	Luxor temple : The Southern Harem of Amun
Thu 20 July	Dr Wes Stein, CSIRO	Smoke and Mirrors — Where to for Clean Energy?
Thu 17 Aug	Hugh Mackay Psychologist, Sociologist and Social Researcher	The changing place of religion in Australia
Thu 28 Sep	Professor Peter Schofield Executive Director and CEO, NeuRA (Neuroscience Research Australia)	Biomarker Changes in Dominantly Inherited Alzheimer's Disease
Thu 19 Oct	Professor Dean Rickles Professor of History and Philosophy of Modern Physics, University of Sydney	Quantum Gravity
Thu 16 Nov	Yik Lung (Jeremy) Chan, University of Technology Sydney	Effects of Maternal Cigarette Smoke Exposure

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Awards 2017

James Cook Medal

Scientia Professor Gordon Parker AO FRANZCP FASSA is the winner of the **James Cook Medal**. He is Professor of Medicine at the University of New South Wales.

Professor Parker's research has been focused on psychiatry, specialising in clinical research in mental health, in particular, depression and bipolar disorder. He was founding Director of the internationally recognised Black Dog Institute, dedicated to understanding, preventing, and treating mental illness. Thus, his contributions have had a major and lasting impact on human welfare in Australia, the Southern Hemisphere and beyond.

The James Cook Medal is awarded from time to time for outstanding contributions to both science and human welfare in and for the Southern Hemisphere.

Edgeworth David Medal

Edgeworth David Medal for 2017 will be awarded to **Dr. Angela Nickerson**. She is a Senior Lecturer in the School of Psychology University of New South Wales, and an emerging international leader in the field of refugee mental health.

Dr Nickerson's research has been highly influential on both the direction of the research field, as well as policy and practice both in Australia and overseas.

Her research has been at the forefront of uncovering the psychological mechanisms that underpin refugee mental health.

The Edgeworth David Medal is awarded each year for distinguished research by a young scientist under the age of 35 years for work done mainly in Australia or for contributing to the advancement of Australian science.

Clarke Medal for Botany

This year's winner of the **Clarke Medal** is **Professor David Keith.** He is Professor of Botany, University of New South Wales and Senior Principal Research Scientist, NSW Office of Environment & Heritage.

Professor Keith is widely regarded as a leading plant ecologist at a state, national, and international level. His standing is founded on diverse contributions to botany, ecology, and conservation biology, both within Australia and globally. These contributions include long-term ecological studies, extensive vegetation surveys and mapping, studies on the ecology of rare and threatened flora, conservation risk analysis for species and ecosystems, applied fire ecology, and most recently a seminal synthesis in a new book on Australian vegetation.

The Clarke Medal is awarded each year for distinguished research in the natural sciences conducted in the Australian Commonwealth and its territories. The fields of botany, geology, and zoology are considered in rotation. For 2017, the medal was awarded in Botany.

History and Philosophy of Science Medal

Professor Peter Godfrey-Smith will receive the **History and Philosophy of Science Medal** for 2017. He is Professor at the School of History and Philosophy of Science at the University of Sydney.

Professor Peter Godfrey-Smith has made seminal contributions to the philosophy of biology, especially evolutionary theory, and to the philosophy of mind, particularly in relation to animal cognition and the evolutionary origins of subjective experience and 'consciousness'.

The Society's History and Philosophy of Science Medal is awarded each year to recognise outstanding achievement in the History and Philosophy of Science, with preference being given to the study of ideas, institutions, and individuals of significance to the practice of the natural sciences in Australia.

Royal Society of New South Wales Scholarships

Three scholarships of $500 plus and a complimentary year of membership of the Society are awarded each year in order to acknowledge outstanding achievements by young researchers in any field of science. Applicants must be enrolled as research students in a university in either NSW or the ACT. This year's winners are:

Grace Causer, PhD Candidate at the University of Wollongong and the Australian Nuclear Science and Technology Organisation. Ms Causer investigates novel and artificial nanomaterials, e.g., spintronic and multiferroic materials, using neutron and X-ray scattering methods. Consequently, these studies could lead to future applications in hydrogen gas sensing, spintronic, memory storage, and logic devices.

Yu-wei Lin, PhD Candidate in the Faculty of Pharmacy, University of Sydney. Mr Lin's area of research is concerned with developing valuable pharmacological information with regards to life-threatening respiratory tract infections caused by the deadly Gram-negative 'superbugs'.

Cara Van Der Wal, PhD candidate at the University of Sydney and the Australian Museum. Her research focuses on a remarkable group of crustaceans known as mantis shrimps. Many species live in Australian waters, but the evolutionary history and diversity of mantis shrimps remain poorly understood. Subsequently, these studies will fill the biological knowledge gap on genetic resources from this group of crustaceans.

Pollock Memorial Lecture

The **Pollock Memorial Lectureship** for 2017 will be awarded to **Professor Andrea Morello FAPS FRSN**, University of New South Wales.

Professor Morello is an internationally recognised leader in quantum science and technology. He has invented and demonstrated all of the fundamental building blocks of a silicon quantum computer, laying the foundations for its practical manufacturing.

The Pollock Memorial Lectureship has been awarded from time to time for research in physics. It is jointly sponsored by the University of Sydney and the Society in memory of Professor J.A. Pollock, Professor of Physics at the University of Sydney (1899-1922) and a member of the Society for 35 years

Poggendorff Lecture

Associate Professor Brent Kaiser will be awarded the **Poggendorff Lectureship** for 2017. He is Professor at the School of Life and Environmental Sciences, University of Sydney.

Professor Kaiser is a molecular plant physiologist whose research into the sustainable use of nitrogen in cereal and legume grain crops has not only advanced the field, but achieved also tangible improvements in agricultural production and environmental stewardship.

The Poggendorf Lecture is awarded every two to three years for research in plant biology and more broadly agriculture.

RSNSW Medal

Dr Donald Hector AO FRSN will be awarded the **RSNSW Medal** for 2017. He is Vice-President of the Society and immediate past President.

Dr Hector's contributions to the RSNSW have been important, extensive and over a number of years. In particular, the recent restructuring of the Society's membership and organisation has allowed the Society to become a true leader of NSW intellectual life.

The Society's Bronze Medal is awarded from time to time to a member of the Society who has made meritorious contributions to the advancement of science, including administration and organisation of scientific endeavour and for services to the Society.

Jak Kelly Award

The winner of the **Jak Kelly Award** for 2017 is Moritz Merklein from the University of Sydney. His research investigates a memory for optical data that is based on sound waves and has the potential to revolutionise next-generation computer chips.

The Jak Kelly Award encourages excellence in postgraduate research in physics. The winner was selected from a short list of candidates who made presentations at a recent joint meeting at UNSW of the Australian Institute of Physics NSW Branch, the Royal Australian Chemical Institute, and the Royal Society of NSW.

The Royal Society of New South Wales

INFORMATION FOR AUTHORS

Details of submission guidelines can be found in the on-line Style Guide for Authors at:
https://royalsoc.org.au/society-publications/information-for-authors

Manuscripts are only accepted in digital format and should be e-mailed to:
journal-ed@royalsoc.org.au

The templates available on the Journal website should be used for preparing manuscripts. Full instructions for preparing submissions are also given on the website.

If the file-size is too large to email it should be placed on a CD-ROM or other digital media and posted to:

The Honorary Secretary (Editorial),
The Royal Society of New South Wales,
PO Box 576,
Crows Nest, NSW 1585
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Manuscripts will be reviewed by the Editor, in consultation with the Editorial Board, to decide whether the paper will be considered for publication in the Journal. Manuscripts are subjected to peer review by at least one independent reviewer. In the event of initial rejection, manuscripts may be sent to other reviewers.

Papers (other than those specially invited by the Editorial Board) will only be considered if the content is either substantially new material that has not been published previously, or is a review of a major research programme. Papers presenting aspects of the historical record of research carried out within Australia are particularly encouraged. In the case of papers presenting new research, the author must certify that the material has not been submitted concurrently elsewhere nor is likely to be published elsewhere in substantially the same form. In the case of papers reviewing a major research programme, the author must certify that the material has not been published substantially in the same form elsewhere and that permission for the Society to publish has been granted by all copyright holders. Letters to the Editor, Discourses, Short Notes and Abstracts of Australian PhD theses may also be submitted for publication. Please contact the Editor if you would like to discuss a possible article for inclusion in the Journal.

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