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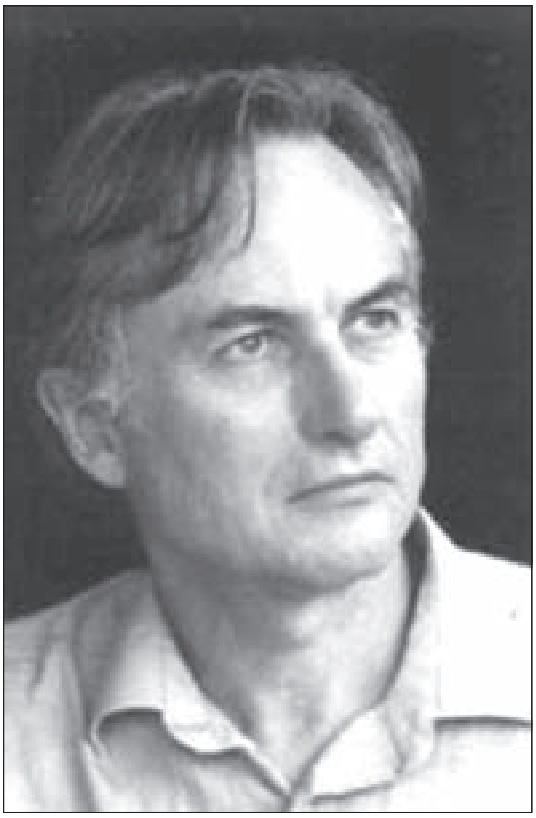

Richard Dawkins, sociobiologist

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A forum for the exchange of views on science and science policy.

Guest Editor: David Lillis
Managing Editor: Allen Petrey
Production Editor: Geoff Gregory

Contents

Cover photo: Richard Dawkins was born in Nairobi in 1941, took a BA at Oxford University in 1962 and a DPhil there in 1966. He was Assistant Professor of Zoology at the University of California at Berkeley 1967-69, then Lecturer in Zoology at Oxford University, and Fellow of New College from 1970. Presently he is the Charles Simonyi Professor of the Public Understanding of Science at Oxford University. Dr Dawkins published his first book, *The Selfish Gene*, in 1976. His other books about evolution, science and sociobiology include *The Extended Phenotype, The Blind Watchmaker, River Out of Eden, Climbing Mount Improbable,* and *Unweaving the Rainbow*.

Instructions to Authors

NZ Science Review provides a forum for the discussion of science policy. It covers science and technology in their broadest sense and their impacts on society and the environment, both favourable and adverse. It also covers science education, science planning, and freedom of information. It is aimed at all scientists and decision makers, and the interested public. Readability and absence of jargon are essential.

Manuscripts on the above topics are welcome, two copies of which should be sent to:

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As well as full papers, short contributions, reports on new developments and conferences, and reviews of books, all in the general areas of interest of the journal, are invited. The journal also accepts reviews of a general nature and research reports.

Full manuscripts (with author's name removed) will be evaluated and authors will be sent copies of the reviewer's comments and a decision on publication. Manuscripts should not normally have appeared in print elsewhere but already published results discussed in the different, special context of the journal will be considered. They should preferably not exceed 2500 words.

To facilitate anonymous review, author's names on manuscripts and any acknowledgement of assistance should be on a detachable cover page. Manuscripts should be accompanied by biographies of not more than 100 words on each author's personal history and current interests. Authors are also expected to supply a suitable passport-size photograph of themselves.

Manuscripts should be typed double-spaced with wide margins on one side of the page. Articles may be submitted in Word for PC, rich text format, or plain text, by e-mail, or on floppy disk or CD-R, but a hardcopy should also be sent so that fidelity may be confirmed. Diagrams and photographs should be on separate files (preferably eps, tif, jpg, all at 300 dpi), not embedded in the text.

All tables and illustrations should be numbered separately – Tables 1, 2, 3, 4, etc., and Figures 1, 2, 3, 4, etc. – and be referred to in the text. Footnotes should be eliminated as far as possible. Diagrams and photographs will be printed in black and white, so symbols should be readily distinguishable without colour, and hatching should be used rather than block shading.

References should preferably be cited by the author–date (Harvard) system as described in the Lincoln University Press *Write Edit Print: Style Manual for Aotearoa New Zealand* (1997), which is also used as the standard for other editorial conventions. This system entails citing each author's surname and the year of publication in the text and an alphabetical listing of all author's cited at the end. Alternative systems may be acceptable provided that they are used accurately and consistently.

Foreword

This issue of *New Zealand Science Review*, the first for 2004, brings together a range of articles, from the analysis of possible carbon credit policies to meet New Zealand's Kyoto Protocol obligations, to current and future policy work at the Royal Society of New Zealand, and recent developments in nanotechnology. We hope that you will find much of interest here.

Sean Devine, former Manager of the Public Good Science Fund and presently Research Fellow at Victoria University, gives us an informative account of Postmodernism, a prevalent world view that embodies a degree of reaction against science and the benefits that science has brought to the world over the last century.

Shaun Hendy, an applied mathematician at Industrial Research Limited, presents a fascinating overview of his theoretical simulations of the behaviour of nano-sized particles (essentially agglomerations of atoms), how the structures of these agglomerations depend on the numbers of atoms within them, and the physics of freezing and melting over very small spatial scales.

Graeme Wake, Professor of Mathematics at Massey University, tells us about a recent meeting of the Mathematics-in-Industry Study Group, held in Auckland during January of this year. The participant mathematicians formed themselves into six subgroups, each of which took up the challenge of developing solutions to problems arising within industry. Graeme's paper underscores the immense value of mathematics in solving otherwise intractable problems and thereby contributing significantly to business success.

Suzi Kerr, of MOTU Research, a policy and economics research agency based in Wellington, discusses the economics of different forms of contract for the trade of carbon credits created through reforestation projects that are intended to meet New Zealand's Kyoto Protocol obligations. Such work is invaluable in clarifying New Zealand's forestry policy response to Kyoto.

Professor David Penny, of Massey University, has written a tongue-in-cheek account of his time as a panellist for the Performance Based Research Fund. He stresses the importance of taking care when completing the assessment forms. Researchers take note!

Jez Weston and Kathleen Logan, newly appointed policy analysts at the Royal Society of New Zealand, are introduced in a report outlining their current policy work and the many projects in which they are becoming involved. We are sure that the Royal Society's emergent policy function will make valuable contributions to New Zealand's innovation system over the next few years.

Vince Gray, member of Council of the New Zealand Association of Scientists, has provided a personal review of historic and current thinking about sociobiology, the study of the social organisation of biological entities. Vince reminds us that evolution takes place at many levels (not simply at the level of the organism), that the survival of mankind is not assured, and that we must promote altruism at every level if we are to be around over the long term.

So, this issue gives you a wide range of interesting science-related articles. Read and enjoy!

David Lillis, Janet Grieve, and Allen Petrey
Council for the New Zealand Association of Scientists

Postmodernism and science

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Introduction

Today's influential intellectuals believe that we live in a postmodern world where, intellectually, science counts for little. Even though postmodernist thought patterns dominate today's political, social, and intellectual agenda, the science community seems ill-informed about postmodernism. Scientists struggle to understand why today's society is unconcerned about evidence-based knowledge, and why superstition and 'crack pot' medical treatments seem to have become the norm.

In this paper I suggest that the underlying postmodernist worldview, developed by intellectuals over the last 40 years, has become a major driver of societal decision-making. I aim to raise the scientific community's awareness of the postmodern debate and to help scientists understand its thought structure. However, I do not focus exclusively on postmodernism's obscurity and inconsistencies. Rather, I suggest that it is **because** postmodernist thought has the ability to provide insights that otherwise might be missed, that it has become so widely embraced. Nevertheless, I also argue that, where postmodernism claims more for itself than it has to give (which is often the case), it should be challenged vigorously.

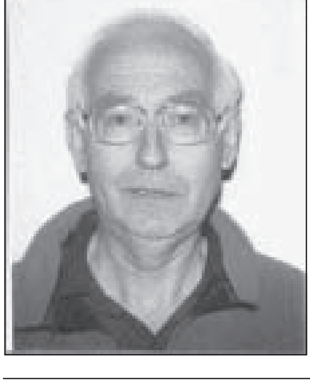
The emergence of postmodernism

Postmodernism evolved as a response to the disillusionment of what is termed the 'modernist' worldview – the over-optimistic worldview that followed the intellectual achievements of the enlightenment. This modernist worldview is characterised by the emergence of science, and a belief that the universe can be understood rationally and that progress is an inevitable consequence of the systematic application of human reason. Postmodernists would argue that the extreme optimism of what they term the 'modern' era was misplaced and that the modernist approach provided the rationale for communism, national socialism and western economic and cultural imperialism. Furthermore, modernism ignored valid understandings from pre-enlightenment times. Postmodernists argue that many of today's power structures and values (e.g. utilitarianism) are grounded in the same arrogant confidence, an arrogance that consolidates power rather than liberates, and that marginalises other approaches to knowledge development.

Postmodernism is not a clearly defined knowledge system. Rather, it is a way of thinking that sees the following disturbing characteristics of the modernist worldview.

- An over-confidence in the rational process to improve the lot of humankind.
- An over-confidence in science or rational analysis as the ultimate form of knowledge. (i.e. postmodernism objects to the view that understandings arising from rational scientific processes are truer than other understandings).
- An over-confidence in progress, whether economic, social or technical. The destructive movements of the 20th Century, and its devastating wars, with the emergence of technologies that can destroy the world, showed that trust in human progress, through education, understanding and managing society, has been ill-founded. Much so-called technological progress may benefit some at the expense of those who carry the cost of such progress, as experienced by increasing pollution and environmental degradation.
- The belief that the modern western civilisation is superior and that other societies need to be transformed by western culture and values.

Indeed, many scientists identify with these concerns, particularly where the over-confidence is ideologically-based and not supported by evidence. For example, Galton's eugenics movement, while ostensibly based on an evolutionary worldview, was not evidence-based, but used science language as a club to support an ideology (see BBC 2001). Indeed, the arrogance of some scientific thinkers has created the climate for the postmodernist reaction. Hopefully, today's science thinkers would reject truth claims made by science outside its sphere of validity. Hence, the scientific objection to the postmodern approach is not that postmodernism questions assumptions or objects to manipulating reason for ideological ends. Rather, the scientific objection to postmodernism is that it does not even try to sift the 'wheat from the chaff', but instead undermines science by rejecting the thought patterns and the associated processes of evidential, rational knowledge building. Rigid postmodernism has thrown the baby out with the bath water!



Sean Devine spent 20 years as a research scientist and science manager in the Physics and Engineering Laboratory DSIR, working in condensed matter physics. With funding cuts to science in the mid-1980s, Sean studied economics on the grounds that 'if you can't beat them join them' and later became manager of the Public Good Science Fund at FRST. After five years in that role he took up a position as Executive Director of the Association of Crown Research Institutes.

He recently moved to Victoria University as a Research Fellow, focusing on the economic effects of technological change.

Effectively, postmodernism denies the validity of the intellectual core of the modernist (i.e. rational) view on the basis that modernity cannot be defended using its own methodologies. Implicit in this attack is a confidence that the postmodern knowledge structure is ultimately more fundamental than the scientific, evidence-based knowledge building, because postmodernism is primarily an understanding about the structure and organisation of the thought process – not an application of one particular (e.g. the scientific) approach.

What, then, is postmodernism?

I came across the postmodernism in the early 1990s while working with social scientists, but could not understand what it was about. I now realise that this was because postmodernism cannot be defined easily in conventional thought categories through a series of definitions or position statements. Postmodernism is more an understanding that is absorbed, rather than learned. It is not just one coherent thought structure; rather, it is a set of perspectives critical of recent knowledge structures. Postmodernism, by coming at issues related to language and subjectivity from 'left field', throws up the relationships and interconnections between the way we 'language' and the power structures that such languaging supports.

The different approaches which all fall under the postmodern umbrella have the following common perspectives

- Things are not what they seem. Behind what a text seems to say are hidden power claims. There is the 'problemisation of subject and author' and 'For what and for whom are we speaking?' In answering these questions, alternative meanings can emerge. Poststructuralism counters the view that in a text the signifiers (i.e. symbols) have defined meanings. Understanding meaning is analogous to searching for definitions in a dictionary, where the definitions refer to other words in a circular fashion. There is no ground to meaning - only differences between meanings. 'Woman' can mean a sexual object, a mother or a victim, depending on the context. Ultimately, meaning only has significance to the interpreter - not the author. Jacques Derrida has developed the concept of 'deconstruction', which is a way of unpacking the hidden meanings of particular texts – what is in the margin and what is left out? For example, labelling someone as a 'worker' may define his or her status as inferior because of the implicit contrast between the 'worker' and the 'boss'. This hidden text, or what is not said, may support power claims not obvious from the written words.
- Truth statements have no validity. Michel Foucault argues that truth grows out of the interests of the powerful ('Truth can support systems of repression'). Rorty (1991) sees truth as the 'intersubjective agreement' within a community. In effect, what we see as truth depends on the community in which we participate. Therefore, each community has its own truth that permits its members to speak a common language and establish a commonly accepted reality.
- Incredulity toward meta-narrative (i.e. a foundational narrative[1] that provides a framework for discerning meaning).

For Lyotard meta-narratives are universal rules used to legitimate beliefs or actions that otherwise would be questionable. The modernist view about the universality of 'the true', 'the beautiful' and 'the good' is, according to Lyotard, untenable. Such narratives impose their meaning, often surreptitiously. For example, the 'market' meta-narrative or framework justifies particular economic structures on the grounds that the market knows best. Instead of appealing to foundational knowledge, postmodernists believe that each community develops its own narrative and this has meaning only to that community. No narrative is more foundational than another.

Eggleton (1987), in objecting to two common meta-narratives, writes: 'Science and philosophy must jettison their grandiose claims and view themselves more modestly as just another narrative'.

The postmodernist view of science

Postmodernists show little interest in science or evidence-based knowledge, as they see these as part of the failed 'modern' worldview with its over-confidence in the rational approach. Their 'Bible' on science is 'The Structure of Scientific Revolutions' by Thomas Kuhn (1970), a one time theoretical physicist. Kuhn's book is recognised as one of the three most significant books of 20th Century thought. In contrast to Popper's somewhat idealistic focus on the intellectual underpinning of science (see, for example, *New Zealand Science Review* 1991; Ormsby 1992), Kuhn focuses on the sociological behaviour of science communities. In doing this, Kuhn generalises about science from his understandings of the history of physics and chemistry in a way that was not even representative of pre-war science, let alone the emerging richness of late 20th Century science. Worse, postmodernists and other academics put their own interpretation on Kuhn to justify a view that science is intellectually inferior.

Interestingly, where Kuhn does offer insights, these apply equally to all academic communities – not just scientists. For example, what academic discipline does not have vested interest groups that use their power to marginalise competing intellectual claims? However, science has one advantage over most other knowledge systems in that there is an external appeal authority - namely, the evidence.

Kuhn calls ground-breaking theories that are non-cumulative (i.e. they have not built on what has gone before) 'paradigms'. The rest of science Kuhn sees as just 'puzzle solving' or 'mopping up'. Only a few break-throughs, such as Newtonian mechanics, atomic theory, the theory of heat, evolution, relativity and quantum mechanics, seem to be true paradigms in Kuhn's terms.[2] The problem is that Kuhn's concept of 'paradigm' and 'cumulative' are unacceptably vague. Surely, every paradigm must have a conceptual leap that is not cumulative; otherwise it would not be a conceptual leap. I think Kuhn also gets into trouble because he is simplistic. My view is that, in

[1] Foundational knowledge is that which underpins other forms of knowledge; i.e. what scientists would see as the 'worldview' with its presuppositions or the (meta) framework of the knowledge system.

[2] Even then, if relativity and quantum mechanics are to be paradigms, the phrase 'non-cumulative' has to have a very specific technical meaning, otherwise a student of quantum mechanics or relativity would not need to have first grasped the major Newtonian concepts. Unfortunately, while Kuhn might have intended 'non-cumulative' to have a specific meaning, his non-scientific followers take the statement to mean science is not building on what has gone before.

practice, lesser paradigms are nested within more foundational paradigms, all building on what has gone before but, at the same time, leaping to something new. Newton himself said that he stood on the shoulders of Kepler, who stood on the shoulders of Copernicus. To be consistent, Kuhn could not recognise the concepts surrounding modern molecular biology as constituting a paradigm, because molecular biology is clearly cumulative, building on the combined streams of atomic theory, structural chemistry as well as evolution, genetics and biochemistry. Therefore, from Kuhn's point of view, the intellectual content of molecular biology is only in the nature of 'puzzle solving'.

Derrida's deconstruction technique, applied to Kuhn's writings, shows why postmodernists see science as intellectually inferior. For example, the implicit message in the phrase; 'normal science is puzzle solving', indicates that science is 'not intellectually significant'.[3] Furthermore, because paradigms are non-cumulative, science is seen as having no integrating structure, but is instead a 'smorgasbord' of knowledge chunks.

Instead of appealing to a meta-framework, postmodernists appeal to their 'gurus' to legitimate their position (i.e. a particular guru's writing can be used as a meta-narrative). The myths derived from Kuhn legitimate the view that there is little point in studying science, its methods or its ability to provide insights.[4] This failure to look at science as it actually is (i.e. the failure to recognise that ultimately science is what scientists do, not what the 'gurus' say they do, is an intellectual weakness of the postmodernist thought system).

Objections to postmodernism

Where postmodernism is used as a set of intellectual tools to shed light on human existence as a form of reflexive inquiry, it has much to offer (as is discussed later). However, where postmodernism acts as if it is 'foundational', a process of inquiry that overarches all other forms of intellectual inquiry, it becomes unaccountable. Strictly, postmodernism can only raise questions, yet in practice it seems to be used inconsistently. Postmodernism is found wanting when its own tools are applied to itself, as the following indicates.

- Postmodernism is sceptical of 'truth statements', yet postmodernist writings drip with truth statements about science, power structures and about other forms of knowledge. For example, the common claim that we live in a postmodern world sounds remarkably like a truth statement. Lyotard (1984, p. 60) makes a truth claim when he says:

  Postmodern science – by concerning itself with such things as undecideables, the limits of precise control, conflicts characterized by incomplete information, 'fracta', catastrophes and pragmatic paradoxes – is theorizing its own evolutions as discontinuous, catastrophic, no – rectifiable and paradoxical. It is changing the meaning of the world 'knowledge', while expressing how such a change can take place. It is producing not the known, but the unknown.

- Postmodernism objects to the use of a meta-narrative or 'foundational knowledge', yet postmodernism is used as a meta-system or a foundational framework against which other forms of knowledge (e.g. scientific knowledge) can be critiqued and marginalised. Lyotard often seems to be working from an anti-science meta-narrative, as he does not argue his position, but treats it as a given. For example, Lyotard blames the student riots of the 1960s on the alienation caused by science, as the following quote shows.

  The resulting demoralisation of researchers and teachers [due to the alienation of science] *is far from negligible; it is well known that during the 1960s, in all of the most highly developed societies,*[5] *it reached such explosive dimensions among those preparing to practice these professions – the students – that there was noticeable decrease in productivity at laboratories and universities unable to protect themselves from its* [presumably the alienation's] *contamination* (Lyotard 1984, p. 7).

  Note his appeal to the phrase: 'it is well known that' to hide the paucity of his argument.

  Again, Lyotard (1984, p. 49–53) attacks the utilitarian trend of (French) universities. However, his inconsistency shows through (p. 50). He believes that knowledge is an end itself (a meta-narrative surely?) and he uses this to legitimate his claim that academics (presumably because of their intellectual genius) should decide their institutional budget.

- Postmodernism objects to claims about reality by postulating that there are many realities. Yet, it acts as if its insights highlight a more fundamental reality; one that can definitively illuminate science's failings.

- Finally, and most critically, strict postmodernism offers no solutions. Once the postmodernist insights have been gained, one may be wiser, but probably sadder. Ultimately, one must appeal to some meta-narrative to determine what action to take in response to these insights. However, practitioners of postmodernism, as is outlined below, often use postmodernism as a club to further covert agenda. Where they do so they are intellectually dishonest.

There are risks where postmodernism becomes the dominant thought pattern for societal decision-making. For good or evil, societal decision-making requires an appeal to some common understanding (i.e. a meta-narrative) about what a better society might be. Yet strict postmodernism cannot do this without betraying its principles. Nevertheless, policy makers in ministries of education, social welfare, health etc, are often committed postmodernists – in which case there is the real danger that their decisions will appeal to covert meta-narratives as their postmodern worldview gives them permission to ignore facts but blinds them to their own framework with its assumptions.

While I have anecdotal evidence that indicates that this happens more than we like to think, I suggest that the evidence lies

[3] Kuhn claims to be pro-science and regrets the anti-science interpretation of his book (Horgan 1996 p45).

[4] For example, a paper I am using in a strategy course (Inkpen and Choudhury 1995, p. 315) makes the following claim: 'It has been well established that scientists systematically ignore disconfirmatory evidence (Kuhn 1970).'

[5] This probably refers to the 1968 student riots in France and the Berkley Free Speech Movement in 1964. The incoherent logic of Lyotard's argument can be seen in the extended passage at http://www.marxists.org/reference/subject/philosophy/works/fr/lyotard.htm.

in the rise of 'political correctness'. Political correctness can only survive within a framework that sees evidence-gathering and rational analysis as irrelevant, but instead refers to a particular unquestioned meta-narrative to justify its claims.

I heard a trade unionist describe how female unionists expected males to sit on the toilet when urinating, because standing to urinate is a sign of male power. While males can denigrate women for not having the same biological attributes, the legitimation of a behaviour requirement, such as that mentioned, appeals to a meta-framework. Unfortunately, no one bothers to establish whether female unionists will be better off as a consequence of such a politically correct requirement. Yet this sort of intellectual manipulation is behind much political correctness and the desire for irrational social engineering.

Another example is the current debate about the merits of phonics and whole word reading. Rayner et al. (2002) point out in *Scientific American* that the evidence shows that, for most people (but not, perhaps, deaf readers), the phonic method is superior, although they endorse using a variety of teaching methods. They state (Rayner et al. 2002, p. 77):

> *If researchers are convinced about the need for phonics instruction, why does the debate continue? Because the controversy is enmeshed in the philosophical differences between the traditional and progressive approaches … the progressives challenge the results of laboratory tests and classroom studies on the basis of a broad philosophical scepticism about the value of such research. They champion student-centred learning and teacher empowerment. Sadly, they fail to realise that these very admirable educational values are equally consistent with the teaching of phonics.*

The use of an implicit meta-narrative 'student-centred learning and teacher empowerment', rather than evidence, to support non-phonic teaching, should not escape the reader's attention. Interestingly, the New Zealand Parliamentary Select Committee on Education and Science (EST 2001) came out in favour of phonic teaching. This may be particularly important for teaching Maori reading, as written Maori is phonetic.

Where postmodernism does throw light

Where postmodernism claims to be foundational, it has little to offer and indeed, as I suggest, will lead intellectual thought up a blind alley. However, where it claims less, it has the potential to offer insights and perspective that otherwise would be more difficult to obtain.[6]

The approach of reflexive inquiry, which looks at a conceptual system or a text as it is, without referring to any external meta-narratives, can allow hidden insights to emerge. Scepticism about what is being said; questioning the obvious; asking 'for whom is the author (of the text) speaking?' allows the not so obvious to emerge.

For example, if we intend to design a new type of aircraft, build a dam, or look at our legal system, we can run the project through a postmodernist template, by suspending our presuppositions about truth, progress and reality, and ask what is really behind this project? What is its real purpose? Who will suffer? The physicist, Margaret Wertheim, although not using postmodernist language, uses a similar approach to argue that the quasi-religious meta-narrative of 'grand physics' marginalises women (Wertheim 1995).

Examples of the kinds of insights that can emerge by applying postmodernism tools to studying organisations can be seen in 'Strategy as Organizing' (Legge 2003). Scientists might well warm to the manner in which postmodernism provides a framework to articulate concerns they may have about their science organisations.

Future of postmodernism as an ideology

Postmodernism in its strict or ideological form has within itself the seeds of its own destruction. As the above argues, it commits the very sins it sees in others. Jean-Paul Sartre provides a further example when he expressed the postmodern argument that, if there was any ethical component to an action, it lay in the exercise of choice, not the moral decision reached. Yet Sartre denied this position when he signed the Algerian Manifesto – a protest against the French occupation of Algeria.

Where postmodernist deconstruction provides evidence that certain beliefs suppress or devalue, the technique cannot reconstruct or offer alternatives without referring to a meta-narrative of some sort. Lyotard has the hope that a sort of 'brainstorming' (called 'parology') between communities with different narratives can create new insights. But why should my community brainstorm with your community when I have my truth, which is as valid as yours? Surely it is better for all to make their meta-narrative or meta-framework transparent and engage with each other at this level rather than retreating into intellectual ghettos. When the meta-narrative is transparent, different knowledge communities can enter dialogue.[7] For example, the book *Feminist Practice & Poststructuralist Theory* (Weedon 1987) is based on the meta-narrative 'Patriarchy is behind female oppression'. Knowing the meta-narrative allows me to work through the issues and have dialogue with the author. However, where postmodernist groups have a covert and unquestioned meta-narrative to further a particular agenda, they are basically deceitful and intellectually irresponsible.

I suggest that, unless postmodernist devotees admit their meta-narratives to allow dialogue, postmodernism will only survive as an ideology in an affluent society able to ignore rational, evidence-based knowledge development.

Final comments

Postmodernism has changed the way intellectuals and western decision-makers think and, as a consequence, they are likely to be reluctant supporters of science or evidence-based policy.

Those of us who do believe that evidence-based rational decision-making is of value, need to ensure that we are not arrogant and that we are amenable to using other tools of critical thinking where these might highlight particular biases and over-confidence. Such biases might arise through lack of evidence, the limits of human reason, or plain human self-interest.

[6] Although one suspects that, where Maori or feminists successfully challenge contemporary power systems, it is because they used evidence to shame the privileged group by appealing to meta-narratives about justice.

[7] I have recently become acquainted with Popper (1994) *The myth of the framework*, which presents this point strongly.

We too must make our meta-narratives clear so that others can critique them.[8] Nevertheless, intellectually, postmodernism does not present a threat to authentic science. Science continues to evolve because it always requires its views to be checked against evidence. Individual scientists have always been comfortable in living with multiple views of the world, such as those of Newtonian mechanics, relativity or quantum mechanics. Indeed, scientists come from every culture and from every belief and metaphysical system. Contrast this trans-national, trans-cultural science with postmodernism - a brand of western intellectual elitism that, if applied unintelligently, could become just another manifestation of western cultural imperialism.

It is not that the postmodern emperor has no clothes; rather, it is that the emperor needs to ensure the embarrassing parts of his anatomy are adequately covered if he is not to be humiliated.

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[8] The metanarrative behind my analysis is: 'Knowledge is one, but we obtain different perspectives on that knowledge depending on the lens we use to view it. The confidence we can have in our knowledge ultimately is based on the confidence we can have in the evidence used to construct it'.

Not so many-body physics

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The size of matter

Take a piece of metal – say the International Prototype Kilogram in Paris – and chop it in two. Apart from the angry metrologists banging on the door, what has changed? Well, we expect no changes in the density, the colour or any other properties of each of the two half-kilogram pieces, except those proportional to the mass (e.g. weight). However, don't stop yet! Divide one of these pieces in two, and then take one of those pieces and divide that in two, and … you get the picture! Once you, or more likely your graduate student, have done this sixty times or so, things finally start to get interesting: the density, colour, melting point (Schmidt et al. 1998) and even the atomic structure (Raoult et al. 1989) of the now only nanometre-sized (10^{-9} m) thousand-atom particles, or *nanoparticles*, will be found to depend quite erratically on size. Welcome to nanoscience!

One of the reasons why nanoscience has attracted such attention (and funding) is that the properties of nanomaterials can be precisely tuned in many instances. Much effort in materials science goes into maximising or minimising material properties (e.g. light-weight ultra-strong composites) or trying to design materials that fill technology gaps (e.g. blue LEDs or full-spectrum solar cells). As we noted above, the properties of nanomaterials depend strongly on size. Thus, there are opportunities to fill performance gaps, extremise desired properties, or even find completely new applications by tuning the size or characteristic length-scale of a nanomaterial.

While the potential rewards are enormous, manipulating such small lumps of matter is difficult, requiring expensive facilities and highly skilled scientists and engineers. One way to get around the expense is to use computer simulation. Today, engineers use computer simulation routinely to help design bridges, racing yachts and jet aircraft, eliminating expensive trial-and-error cycles in the design process. Nanotechnologists are using computer simulation for this very reason. As we attempt to manipulate matter on scales well below the wavelength of light, computer simulation can provide valuable insight into processes that are effectively invisible.

This article is a review of some recent simulation studies of metal nanoparticles. Nanoparticles are of interest, not only for their unique properties, but also because they can be used as building blocks for nanodevices (Schmelzer at al. 2002). Many of the investigations described here have been motivated by a strong experimental programme in nanoparticle science at the University of Canterbury (Hyslop et al. 2001). However, this article will focus on how computer simulation of nanoparticles has led to the discovery of new structures that have no analogue in bulk materials (Hendy & Doye 2002), strange melting behaviour that appears to contradict the laws of thermodynamics, and how solid nanoparticles fuse together to produce larger structures (Hendy et al. 2003).

The computational laboratory

> *The fundamental laws necessary for the mathematical treatment of large parts of physics and the whole of chemistry are thus fully known, and the difficulty lies only in the fact that the applications of these laws leads to equations that are too complex to be solved* (Paul Dirac 1929).

What Dirac did not foresee was the advent of modern computing and a host of new computational techniques that allow us today to solve equations that describe the behaviour of materials at an atomic scale with remarkable accuracy. Computer simulation of molecular dynamics has been made practicable by the arrival of modern computing. Typically, Newton's equations of motion are solved for hundreds, thousands or even millions of interacting atoms. The forces between the atoms are either approximated using an effective interatomic potential (such as the Lennard-Jones potential), or by calculating the quantum mechanical behaviour of the electrons in the atoms.

In the following sections we will use computer simulation of molecular dynamics to study lead nanoparticles with sizes from 1 to 10 nm. The forces between atoms are modelled using a 'glue-potential' (Lim et al. 1992), which approximates the many-body character of metallic bonding. To follow the behaviour of a 1000-atom nanoparticle in this approximation for just a nanosecond (10^{-9} s) of simulated time can take several hours of computer time. Fortunately, many of the processes we are interested in (although by no means all) occur over nanosecond timescales. Such processes are amenable to study using this technique.

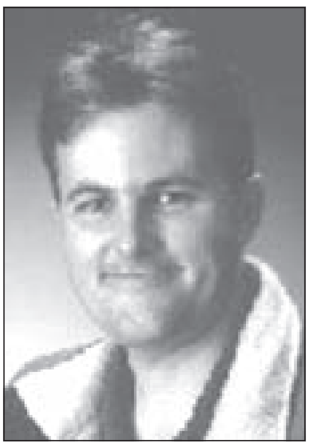
Surface tension rules

What happens when we try to build objects out of clusters? As a simple computational experiment, we can place two solid 1.6 nm lead clusters in contact (approximately one lattice constant apart) and follow what happens using a molecular dynamics simulation (Hendy et al. 2003). Figure 1 shows a sequence of snapshots from the simulation, arranged so that time runs from the top left to bottom right as one would read text on a page. The two solid clusters form a neck in a matter of picoseconds (10^{-12} s), and have fused to form a larger solid cluster within a nanosecond.

In the macroscopic world, this type of behaviour is characteristic of liquids rather than solids. In both solids and liquids, atoms at the surface have fewer bonds with neighbouring atoms and are consequently at a higher energy than those in the interior. In other words surfaces cost energy. The relative cost in energy due to a surface is approximately proportional to the curvature of that surface. For a spherical droplet or particle, the surface curvature is inversely proportional to its radius, R (i.e. curvature ~ 1/R). Thus, by fusing, two spherical droplets or particles increase their radius, reduce their surface curvature and thus reduce the proportion of energy stored in their surface. The force that drives the reduction in surface curvature is called 'surface tension'.

In macroscopic liquids, the fusion process is frequently observed because the atoms or molecules in a liquid are extremely mobile (think of water droplets on a pane of glass). The atoms are free to rearrange themselves to minimise the surface energy. Atoms in solids are much less mobile as they have to squeeze through rigid lattices in order to diffuse. In ordinary circumstances, we will see only negligible amounts of fusion between macroscopic solid objects over a human lifetime.

However, nanoscale objects, whether solid or liquid, have large curvatures, since R ~ 1–100 nm. A very large amount of energy is stored in their surfaces. Furthermore, this relatively large surface area also makes the atoms in a nanoparticle more mobile – diffusion on a solid surface is much faster than through the interior of a solid. It also helps that the atoms don't have far to go – thus, fusion occurs extremely rapidly!



Shaun completed an honours degree in Mathematical Physics at Massey University in Palmerston North in 1993. In 1994 he began studies for a PhD in Physics at the University of Alberta in Edmonton, Canada. Shaun graduated in 1998 and returned to New Zealand to take up a NZ Science and Technology Post-Doctoral Fellowship at Industrial Research Limited in Lower Hutt. Today Shaun holds a joint position at Industrial Research and Victoria University, and is an investigator in the MacDiarmid Institute. Shaun's current research interests are in computational physics and materials modelling, particularly in nanotechnology, although in the past he has worked on wool growth, granular flow, black holes and gravitational waves.

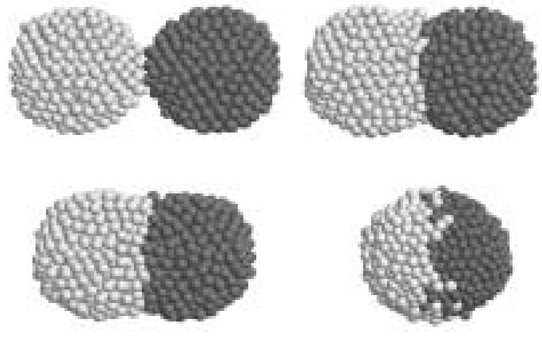


Figure 1. Snapshots showing the results of placing two solid 1.6 nm clusters in contact. Within a nanosecond the clusters have coalesced to form one larger, roughly spherical cluster.

Surface tension can present a problem if we wish to build nanoscale metal objects such as wires that have a higher surface curvature than a sphere. Any such nanowire will want to relax to a sphere to reduce its surface energy in the same way that our two clusters fused to give a single spherical particle. Indeed, this tendency for particles to fuse has proved a technological stumbling block for high-density storage using magnetic nanoparticles (Sun et al. 2002). Often, special measures need to be taken to prevent particle fusion.

We have seen how surfaces can play an important role in nanoscale materials (nanomaterials). In bulk materials, the tiny surface area to volume ratio substantially diminishes the role of surfaces. In nanomaterials this ratio is very high, and these materials can store a large amount of energy as surface curvature. In the next section, we will examine how this surface energy can alter the atomic structure of a nanoparticle.

The five-fold way

Crystals with a five-fold symmetry, such as icosahedra or decahedra (see Figure 2), are uncommon in nature. This is because their atoms cannot repeat a five-fold symmetric lattice indefinitely to form macroscopic space-filling structures. As the sizes of these crystals grow, gaps widen between the atomic lattice sites and this causes strain to build up. Eventually, this strain will force the crystal to revert to other crystal structures that can repeat indefinitely. However, if a nanoparticle crystal can reduce its surface energy by adopting a five-fold symmetric structure, then this may overcome the internal strain.

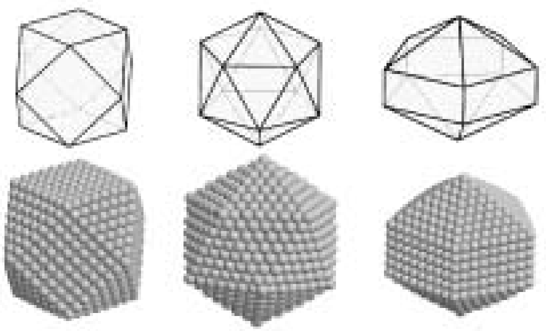


Figure 2. From left to right: a cuboctahedron, an icosahedron and a truncated decahedron.

This is precisely what happens in many metals with a face-centred cubic crystal structure. Figure 2 shows some examples of crystal structures. The structure on the left is a cuboctahedron which has face-centred cubic lattice structure that is space-filling. The cuboctahedron has two types of facet at the surface: a triangular facet and a square facet. On the triangular facets, the surface atoms have nine near neighbours (six on the surface and three below), while the atoms on square facets have eight near neighbours (four on the surface and four below). Atoms on the triangular facets are close-packed: they have more near neighbour bonds (nine versus eight), making them energetically more stable than their counterparts on the square faces.

In Figure 2, the crystal in the centre is an icosahedron. This structure has a five-fold symmetry and is not space-filling (as we discussed above). However, on the surface of the icosahedron all the facets are close-packed. If the particle is small enough, the favourable surface energy of the close-packed facets will overcome the strain caused by the five-fold crystal structure. In face-centred cubic metals, such as gold and silver, icosahedral nanoparticles occur for just this reason.

However, in lead nanocrystals, the situation appears to be considerably more complex. Molecular dynamics simulations have revealed new types of icosahedral structures (Hendy & Hall 2001) with more complex surfaces. The icosahedron shown in Figure 2 can be constructed from twenty face-centred cubic tetrahedra (see Figure 3). However, if combinations of close-packed tetrahedra are used that have stacking faults (i.e. misalignments of crystal planes, see Figure 5), we obtain highly stable configurations. These stacking faults introduce new strains into the crystal, but more than compensate for this by increasing the number of second-nearest neighbour bonds of the surface atoms.

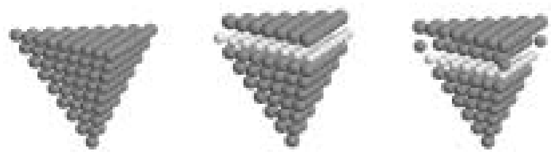
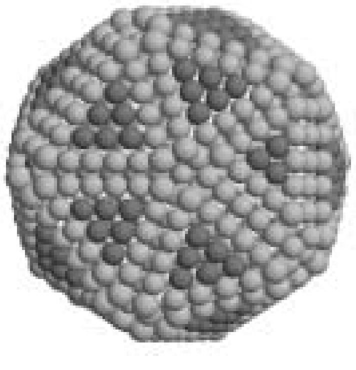


Figure 3. Close-packed tetrahedra from left to right: a perfect fcc tetrahedron, a fcc tetrahedron with a stacking fault in the penultimate layer (coloured white) and a fcc tetrahedron with a twin-plane in the third layer (coloured white).

Figure 4 shows one of the possible icosahedra that can be assembled from these tetrahedra. In fact, there are a vast number of possible structures like this one. It can be shown that, using the three tetrahedra from Figure 3, one can construct 58,130,055 different icosahedra (Hendy & Doye 2002)! Furthermore, many of these icosahedra have chirality: that is, they come in left and right-handed pairs, much like many organic molecules.

Thus, there is a rich variety of structures available to nanoparticles as a result of the balance between surface energy and internal strains. Atomic structure is an important determinant of the properties of a substance. It is likely that there are many nanoparticles with novel structures, and hence novel properties, waiting to be discovered.

Figure 4. A new type of icosahedral structure. The five-fold symmetry is clearly visible.



How big is a liquid?

The properties of a material depend on whether it is a solid, liquid or gas. At the macroscale we can alter the temperature or pressure of a substance, forcing it to undergo a phase transition such as melting, freezing or boiling, for example. However, in traditional thermodynamics, phases and phase transitions are features of systems with very large numbers of atoms, $N \sim 10^{23}$. Obviously, it makes little sense to talk about phases and phase transitions when $N \sim 1$. Does traditional thermodynamics even apply to nanoscale systems where $N \sim 10^2$–$10^6 << 10^{23}$?

We can investigate this question using molecular dynamics simulations. A good way to proceed is to examine the caloric curve for a nanoparticle, or in other words the temperature, T, of the particle as a function of total energy, E. Figure 5 shows a caloric curve for a 931-atom lead particle with a radius of 1.9 nm. The curve is calculated using a sequence of molecular dynamics simulations, where the energy, E, is kept constant during each simulation, but is increased slightly between simulations. A temperature, T, is obtained by calculating the average kinetic energy of the atoms in a cluster over the duration of each constant energy simulation. In this way we can determine the dependence of T on E and plot the caloric curve.

We start the sequence of simulations with a solid particle (such as that shown in Figure 4) at a temperature close to 0K. As we slowly add energy to the system (moving from left to right across the E-axis of Figure 6), the temperature increases. In fact, the slope of this curve is just the heat capacity. However, between E = –1.69 eV/atom and E = –1.68 eV/atom, there are some large fluctuations in temperature, followed by a sudden drop in temperature. This sudden drop indicates the onset of the melting transition; the drop in temperature is caused by the conversion of kinetic energy into latent heat of melting. We clearly see a melting transition in this system.

However, an interesting feature of Figure 5 is that at a temperature of 460K the cluster can be either solid (at an energy of –1.71 eV/atom) *or* liquid (at an energy of –1.68 eV/atom). In fact, the melting temperature (~ 500K) and the freezing temperature (~ 450K) are not the same! We also note that both these temperatures are substantially smaller than the melting-freezing temperature of bulk lead (~ 600K). Both of these observations are well-known features of 'small' systems (Honeycutt & Andersen 1987).

Now let's consider the simulated caloric curve of a slightly larger particle with 1427 atoms and a radius of 2.2 nm, as shown in Figure 6. This small increase in size produces quite different behaviour. We see two sudden drops in temperature in the caloric curve, indicating the presence of two phase transitions. It turns out that the first transition not a full melting transition: it is a transition from a solid state to a state that is a mixture of coexisting solid and liquid phases (see Figure 7).

Note that as we continue to increase the energy of our simulated particle (moving to the right of the first temperature jump in Figure 6), the temperature, while fluctuating strongly, ceases to increase steadily. Closer scrutiny shows that the temperature decreases slightly over this intermediate interval. Thus, the particle has a negative heat capacity in this region of the caloric curve – as we add energy to the system it cools! Finally, there is a further drop in temperature indicating a second phase transition. Figure 7 shows a sequence of snapshots taken from this intermediate region of the caloric curve. Atoms have been coloured according to their mobility: high mobility atoms are dark and are in the liquid phase, while low mobility atoms are light and are in the solid phase. As we move from the top left to the bottom right snapshot, we are moving to higher energy states: the temperature does not increase as we do this because

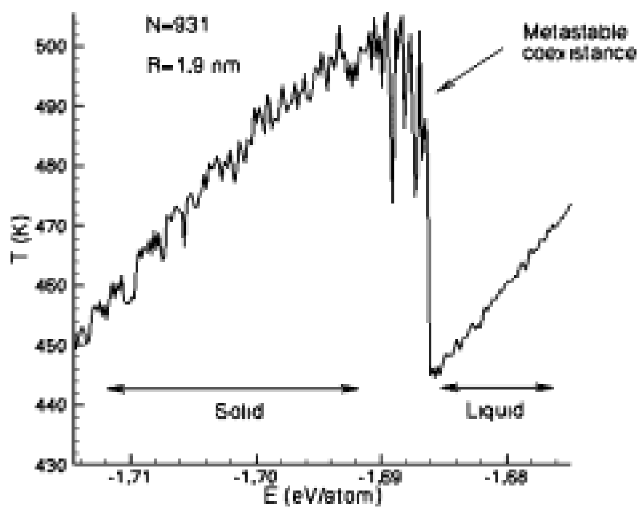


Figure 5. Caloric curve (temperature v. energy) of an isolated 931-atom lead cluster.

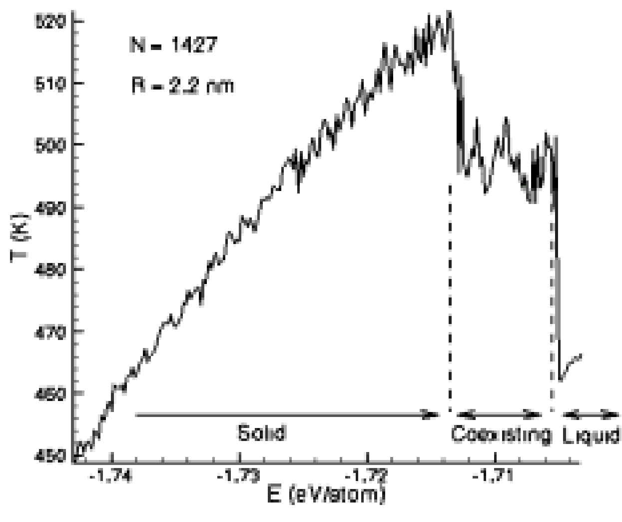


Figure 6. Caloric curve (temperature v. energy) of an isolated 1427-atom lead cluster.

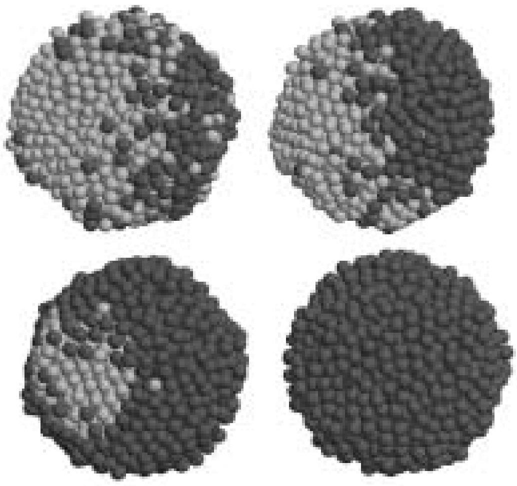


Figure 7. A sequence of cluster states where the solid phase and liquid phase coexist. Atoms in solid regions are lightly shaded and atoms in liquid regions are darkly shaded.

the energy is being used to convert more and more of the atoms into the liquid state. Finally, this coexisting solid-liquid state becomes unstable, and a second phase transition occurs as the particle becomes completely liquid.

Why did we did not see this solid-liquid coexistence region in the caloric curve for the smaller 1.9 nm cluster? It turns out that the coexisting solid-liquid state is only *metastable* at this size (i.e. the state is only a local, not global, maximum of the entropy) - a rough estimate suggests it becomes stable (i.e. a global maxima) only above 2 nm. Looking back at Figure 5, note the large fluctuations in temperature before the transition. These temperature fluctuations are due to 'hops' between the stable solid state and this metastable coexisting solid-liquid state. The occurrence of these 'hops' is in fact a finite-size effect as the cluster explores a relatively small phase space (Honeywell & Andersen 1987).

Thus, we conclude that traditional thermodynamic concepts, such as phases and phase transitions, do apply to nanoscale clusters. Somewhat paradoxically, however, the behaviour of such 'small' systems ($N \sim 10^3$) at phase transitions can be considerably more complex than in bulk thermodynamics ($N \sim 10^{23}$).

Conclusions

Over the last few decades the electronics industry has been relentlessly driving semiconductor technology towards the nanoscale in an effort to pack more and more devices into a smaller area. Your next PC will probably contain chips with features engineered to within 100 nanometres (Hutcheson 2004). As a result it will be faster and will store more data than the computer on your desk now.

In this article we have used computer simulation to explore the science of nanoscale metal particles. To engineer and control the nanochips and nanowires of the future, we will need to know how nanometre-sized objects behave. Computer simulation can be a powerful tool that can help us both to visualise and forge an understanding of the counter-intuitive and exotic properties of nanomaterials.

Acknowledgements

I would like to thank Dr Blair Hall (IRL), Dr Simon Brown (University of Canterbury), Dr Michael Hyslop (University of Canterbury) and Dr Jonathan Doye (Cambridge) for their collaboration on aspects of the research reviewed here. This work has been funded by IRL-NSOF contracts 00-PIO-005 and 01-CEO-01, and the MacDiarmid Institute for Advanced Materials and Nanotechnology. Much of the computing has been carried out using the MacDiarmid Institute high-performance computing facilities.

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The numbers game: Mathematics-in-Industry Study Group comes to New Zealand

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After 20 years of being hosted very successfully in Australia, the annual Mathematics-in-Industry Study Group (MISG) moved across the Tasman to Auckland, and was held there on 26–30 January 2004, the week before the ANZIAM (Australian/NZ Industrial & Applied Mathematics group) 2004 Conference in Hobart. While held in Australia this initiative had been hugely successful in bringing the power of mathematics, statistics and scientific computing to solve problems arising in industry. It is based on a model which has operated in Europe, the European Study Group in Industry, which began in Oxford in the late 1960s. On average, six to eight problems are brought from around Australasia every year, with significant involvement from New Zealand. The mix of academics, scientists and industry people provides a fertile environment for creative and detailed analysis of problems. Many industries in New Zealand do not have this sort of expertise in-house, as it were, so the Study Groups provide a unique opportunity for them to obtain fresh insights to their own operation.

This year the Study Group (MISG2004) was organised by the newly formed Centre for Mathematics in Industry at Massey University in Albany, Auckland, and was located at the University of Auckland's city campus. It brought together nearly 140 delegates from all parts of the world: international contributors included invitees Paul Dellar from OCIAM, Oxford, UK; John King from Nottingham, UK; together with five from the Korea Advanced Institute for Science and Technology (KAIST), including three students. Many other Asian countries were represented. In addition to the most important brainstorming sessions, a student workshop was held (speakers Alan Conaghan – 'Pavement Modelling', Graeme Wake – 'Industrial Mathematics' and John King – 'Mathematics in Medicine'). Plenaries were given by Ray Hoare on Software developments and Paul Dellar on Combustion waves/ UK Study Group problems; and a ferry/restaurant excursion was held one warm summer evening. More details can be found on the website: http://misg2004.massey.ac.nz, including some of the key addresses given. Six industrial problems were considered:

- Strip temperature in a metal coating line annealing furnace (NZ Steel) – to predict and control strip temperature during annealing which is essential for ensuring product quality.

  Moderators: Drs Mark McGuinness (Victoria University) and Steve Taylor (University of Auckland).

- Modelling of a poultry shed (NRM/Tegel) – to provide underpinning decision support for the modelling of the energy exchange between the growing chickens and their shed environment.

  Moderators: Professor Robert McKibbin (Massey University, Auckland) and Dr Andy Wilkins (Canesis Network).

- Forecasting wind farm generation (Transpower NZ Ltd) – develop an algorithm to forecast wind farm electrical output from real-time to a day ahead, considering operational and meteorological characteristics.

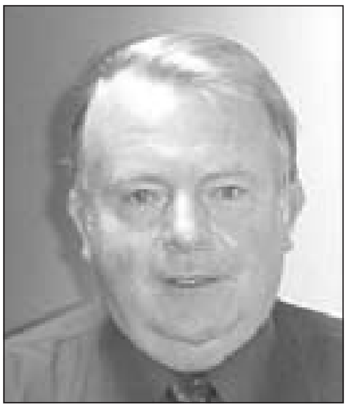
  Moderators: Dr Tasos Tsoularis (Massey University, Auckland) and Dr Bill Whiten (University of Queensland).

- Earthquake damage in underground roadways (Solid Energy Ltd) – provide a model that can relate risk and damage to underground roadways occurring from earthquake waves of varying depth, intensity and incidence.

  Moderators: Associate-Professor Tim Marchant (University of Wollongong) and Dr Graham Weir (Industrial Research Ltd).

MISG 2004 was sponsored by ANZIAM, NZ Mathematical Society, Massey and Auckland Universities, Hoare Research Software Ltd, Canesis Network Ltd, Industrial Research Ltd, Pavement Management Services and Transfield Services. Each participating company named above provided logistical and financial support, all of which is gratefully acknowledged.

Buoyed by the success of MISG2004 we are, as agreed by ANZIAM, planning for MISG2005, which will be held in Auckland, 24–28 January 2005.



Graeme Wake is Professor of Industrial Mathematics at Massey University's Albany campus. He is Director of the Mathematics-In-Industry Workshop, which serves as an interface between industry (interpreted very broadly to include the biological and financial industries as well as the traditional engineering ones) and mathematicians. The Centre for Mathematics in Industry ran MISG2004 on behalf of ANZIAM (Australian/NZ Industrial & Applied Mathematics group). Graeme has held Chairs in Applied Mathematics at other New Zealand universities and was awarded the Association's Marsden Medal in 1999 for contributions to mathematics and its applications in New Zealand. In 2001/02 he held a one-year Visiting Fellowship at All Souls' College, Oxford, while collaborating with colleagues in Oxford University's Centre for Industrial and Applied Mathematics, which had pioneered this sort of activity in the 1960s. At that time Graeme was a postdoctoral fellow there.

- Dispersion rates of wilding trees (Environment Canterbury) – provide a predictive model determining propagation rates of wilding trees as a function of environmental parameters so as to assist in planting and control strategies.

  Moderators: Dr Heather North (Landcare Research Ltd) and Associate-Professor Mick Roberts (Massey University, Auckland).

- Optimal sorting of product into fixed weight packaging (Compac Sorting Equipment Ltd) – develop a robust routine for calculating categories of produce by weight and develop the software for implementation, using a 'learning by experience' algorithm.

  Moderators: Dr Phil Kilby (CSIRO, Australia) and Dr Clive Marsh (Canesis Network).

MISG2004 was a resounding success and gave Industrial Mathematics a significant boost in New Zealand, simultaneously providing the annual ANZIAM MISG event in this area. The picture below shows the Director, Professor Graeme Wake, with NZ Steel representatives Phillip Bagshaw (centre) and Nebojsa Joveljic, along with Professor Chang-Ock Lee from KAIST. The moderators (not shown) for this problem were Mark McGuinness from VUW, Wellington, and Steve Taylor from the University of Auckland.

Although it is too early to say much about the final achievements, progress was made on each problem and some downstream collaborations are being nurtured. The latter were strongly encouraged, but not required, by the MISG organisers. The Proceedings of MISG2004 are to be published by our Centre by the end of 2004 and the Equation-free Summaries will be available mid-year, both from: g.c.wake@massey.ac.nz A summary of the six problem outcomes is provided below.

Problem 1

New Zealand Steel (NZS) uses a unique process to convert New Zealand iron-sand into steel sheet products at its Glenbrook mill (near Auckland). Traditional galvanised steel (Galvsteel) and the new product, Zincalume, are produced in a range of dimensions, grades and coating weights. The steel strip is annealed prior to being coated, by heating to a predetermined temperature for a definite time. Annealing produces desirable changes in the crystalline structure of the steel, allowing NZS to tailor its strength and ductility.

Strips of steel sheet are passed through a 150 m long, 4.6 MW electric radiant furnace at speeds of up to 130 m per minute in order to achieve the strip temperatures required for annealing and subsequent coating. The temperature along the furnace is controlled by varying the power supplied to the heating elements and through the use of cooling tubes. The cooling tubes are located in the last half of the furnace and consist of steel tubes through which ambient air is pumped. It is important that the steel exits the furnace at the correct temperature for the coating that is applied at the exit point. The line speed through the furnace is reduced for strips of large thickness and width in order to achieve the required temperatures. At the beginning of the annealing–coating line there is an automatic welding process which welds the beginning of a new coil of steel sheet to the end of its predecessor, allowing the line to run continuously.

In each of the twenty zones of the furnace, thermocouples are located in steel tubes, and are used to measure furnace temperature. The thermocouple temperatures are compared with desired temperature set-points, and the heating elements are controlled accordingly. Steel strip temperature is also measured using non-contact pyrometers at three positions in the furnace.

If there is no variation in strip dimensions and annealing settings then the line is able to run at a *steady state*, with furnace temperatures remaining steady at the desired thermocouple settings. NZS has already developed a mathematical model of furnace and strip temperatures for this steady state operation. Challenges occur when there is variation in strip dimensions or annealing settings because the furnace-strip system has a large amount of thermal inertia. Consequently, the line is in a *transient* state for up to 50% of its operation, with varying effects on quality control of the product.

Two improvements are planned for the line in the very near future: a 3 MW induction heater and a gas jet cooler. The induction heater is capable of heating the strip quite rapidly. The steel strip will pass directly from the induction heater into the radiant furnace. The extra heating power should allow the system to achieve greater line speeds for strips of large thickness and width. Further, with its more rapid response, the induction heater has the potential to reduce the time spent in transient modes of operation. In the gas jet cooler, which will replace part of the existing cooling zone, cooled furnace gas is blown directly onto the steel strip. The new cooler section is expected to respond more rapidly than the existing cooling tubes, giving more precise control of dipping temperatures.

Developing a solution

NZS set the following tasks for the Study Group:

- Develop a mathematical model for transient furnace conditions.
- Investigate the accuracy of the existing steady state model.
- Predict transient strip temperatures for actual production schedules with changes in product dimension, steel grade and furnace temperature settings.
- Couple the temperature model to a metallurgical model.

The Group focused first on modelling the temperature of the steel strip, and soon discovered that this can be modelled accurately as a function of time and just one spatial coordinate, the distance from the entry point of the furnace. Temperatures equilibrate rapidly across the thickness of the steel. Thermal diffusion along the strip was found to be negligible for the length of time that any part of the strip was in the furnace.

This strip model led to a steady state model for the furnace-strip system which took into account the power supplied by heating elements. The Group then compared this to NZS's steady state model. The models differ in that MISG's model allows for continuous changes in temperature along the length of the furnace, while NZS's model is discrete, involving one value of strip temperature and one value of the furnace (wall) temperature for each of the furnace's twenty zones. Our calculations indicated that the models were in good agreement, confirming the accuracy of the NZS steady-state model.

Next, the Group studied the heating of the furnace walls and calculated that, while it would take hundreds of hours for bulk changes to wall temperatures, the inner surfaces of the walls heat up rather quickly. They respond to radiation changes on a time scale of about one minute, and to a depth of only a few millimetres. This response is too rapid to account for the observation that the furnace typically takes five minutes to equilibrate, so attention was then shifted to the steel hearth rolls (the rollers which carry the strip along the furnace), to see if they could be the main source of thermal inertia within the furnace. Preliminary calculations indicated that the hearth rolls do indeed respond to temperature changes on the correct time scale. A transient model for steel strip temperature was developed that took account of the hearth rolls.

During the meeting the Group realised the importance of *view factors*. These factors need to be calculated to accurately model the radiation exchange between the steel strip, heating elements, furnace walls, cooling tubes, hearth rolls and thermocouple tubes. This will improve the accuracy of the transient model for the temperature of the steel strip, by giving a more accurate understanding of the radiation environment experienced by the steel strip.

The thermocouple tubes house the thermocouples which are used to estimate the furnace temperature in each zone of the furnace. They play a vital role, as they are used to control the power fed to the heating elements. The temperature measured by the thermocouples is not the true furnace temperature, which is needed for accurate calculation of steel strip temperature, in both the transient and the steady-state models. A calculation of view factors for these tubes will give much better information on the true furnace temperature than is presently available.

Problem 2

Tegel Foods is New Zealand's leading producer and supplier of poultry products, providing an extensive range of quality poultry products to New Zealanders for over thirty years. Tegel is part of the Heinz-Wattie group of companies, owned by multinational food producer, HJ Heinz Co. Tegel Foods began operations as a department of General Foods Corporation in 1966, and now employs approximately 1700 people at its sites throughout New Zealand.

Tegel Foods is a fully integrated poultry producer involved in breeding, hatching, feeding, growing, processing and marketing of chicken and turkey in New Zealand. Its product range includes fresh, frozen and cooked whole chickens and fresh and frozen chicken portions. NRM New Zealand markets all feed and animal health products that are sold externally.

The problem presented by Tegel was specifically to model the energy exchange between the chickens and their shed environment in order to better understand and control the shed climate and thereby maximize growth rate.

A typical shed has chickens placed as day-old chicks at a stocking density of about 21 birds per square metre. They are reared on a concrete floor (about 15 cm thick), with a 5 cm layer of dry wood shavings spread as 'litter'. This litter remains with the flock for the duration of the batch, composting down to a friable litter material consistent with 50% sawdust mixed with 50% dry garden soil. The sheds are of the 'controlled environment' type, and the birds are grown within a specific temperature profile as they get older. The shed temperature control starts at 32°C at the day of placement, reducing by about 0.4° per day to 20°C by the time the birds reach final processing age (average 37 days). The chickens have unlimited access to feed and water, and grow to a specific growth profile with target weight-for-age expectations. Specific air exchange requirements are necessary to maintain a shed environment acceptable for animal welfare and performance parameters. Water generated into vapour/humidity, through evaporation, and carbon dioxide are the predominant waste products that must be removed.

Prior to placing the chicks, the moisture content of the dry wood shavings is close to 5%. By the end of the growing cycle the litter moisture is ideally no more than 20%. Water accumulation in the litter is insignificant compared to total water throughput during the run. The air exchange is determined by total biomass within the shed and therefore increases throughout the life of the flock. Failure to remove sufficient waste air leads to 'wet litter' which causes welfare problems as well as reduction in performance (expressed as low feed intakes, low weight gains and poorer feed conversion).

As the birds grow, progressively generating their own body heat, the supplementary heat requirement in the shed decreases, and the need to remove heat from the shed starts to overlap. This transition from a heating to a cooling mode is influenced strongly by the weather conditions outside the shed, combined with insulation values of the shed, weight for the age of the flock, and target shed environment temperature.

These daily shed temperature targets are based on achieving the optimum comfort of the birds at every stage. However, as the biomass increases and the influence of heat build-up occurs at floor level, then cooling requirements become harder to formulate on a mathematical basis. Daily temperature monitoring normally measures ambient air temperature 30 cm above the birds' heads. This temperature is therefore not an accurate temperature requirement but an assumption based on visual flock behaviour. This temperature perceived by the birds is a combination of ambient shed temperature, relative humidity, air flow, metabolic heat production and litter temperature.

Developing a solution

The modelling of the shed environment's inputs and outputs will be particularly valuable for assessing three fundamental inputs of economic importance: feed nutrient density in terms of energy formulation, heating in terms of gas and power use, and heat removal by extraction fans. Optimisation of liveweight gain and feed conversion potential are the end targets.

The important variables needing careful consideration include:

- The temperature and relative humidity outside the shed.
- Supplementary heating into the shed.
- Energy and nutrient density of feed consumed by the chickens.
- Increase in biomass within the shed.
- Heat accumulation and storage in the litter and floor under the chickens from biomass heat generation.
- Heat generated by the composting effect of the litter bed.
- Increase in the insulating effect of birds on litter heat from increasing biomass.
- Effect of air flow on heat transfer.

The MISG group found that Tegel's farmers raise their chickens in sheds that are roughly 15 m wide, 80 m long and 3.5 m high. Between 30 000 and 40 000 one-day-old chickens are introduced to the shed, where they are kept with unrestricted access to food and water for between 30 and 40 days, by which time they are between 2 and 3 kg in weight.

The shed floor is made of concrete. On this is the litter, which is initially wood shavings which then gets mixed with chicken manure, a good deal of which is excreted water which must be removed by ventilation. The shed ceiling and walls are well insulated. When the chicks are under 2 weeks old the shed is heated to between 30 and 35°C, with minimal ventilation. After that time the chickens are weaned off the heat, and the shed may be intensively ventilated, depending on the interior and exterior climatic conditions.

A field trip to one of Tegel's sheds convinced us that the shed could be treated fairly accurately as a homogeneous structure; the air seemed to be well-mixed and the chickens and litter were spread evenly across the shed floor. Therefore, our model of the situation consisted of stratified layers: at the bottom was the soil below the shed, then the concrete and then the litter; above that was the chicken layer, then the internal air, the shell of the shed, and finally the external air.

Our model included the temperature of the external air, the internal air, the chickens, the litter, the concrete floor, and the underlying soil. It also included the relative humidity (RH) of the external air, the internal air and the moisture content of the litter.

The main input of heat into the system was through the metabolism of the chickens. Experimental data suggested that a sufficiently precise model of a chicken is that its heat and moisture output are proportional to the surface area of its lung. A typical 2 kg bird produces roughly 10 W of sensible heat and respires 0.28 kg of water per day. For a shed of 30 000 birds, this represents about 8 tonnes/day, or 0.1 kg/s.

The heat from the chicken passes into the air, but is also used to evaporate moisture from the litter. Much of this is vaporised because of the heat input from the chickens and the high water activity of the droppings but, occasionally, if the shed is inadequately ventilated, the water builds up and the litter becomes uncomfortably saturated.

Heat also passes through to the concrete and the underlying soil. Since the shed is virtually in thermal equilibrium at all times, a simple calculation revealed that roughly 1W per chicken is conducted through to the ground. Similarly, in climatic conditions typical of Auckland, roughly 1W per chicken is conducted through the shed wall and roof. This leaves about 8 W per bird, or a total of about 240 kW of heat, to be removed by ventilation.

The group made a sample calculation based on an air speed of 1 m/s provided by the ventilation fans. With ambient (outside) air conditions of 20°C and a relative humidity of 60%, the expelled air was calculated to be at 20°C with a RH of 70%. This provided a water uptake of 0.1 kg/s and a heat gain of 235 kW, which matched the sample data closely (see above). This was very encouraging, as it showed that a simulation of the thermodynamics and psychrometry of the shed environment produced feasible results.

The rate of food and water intake was also investigated using Tegel's data. We found that the chickens' intake was proportional to their surface area, assuming that they were spherical – remarkably, this latter assumption appears to be fairly good! The rate of growth appeared to be quadratic with age. A model for the heat production and water respiration rate of a typical chicken was developed, based on physical principles. Perusal of actual data on chicken weight vs. feed and water intake led to some initial simple models for growth rate as a function of mass. These models will be refined for the final write-up.

Industry representative, John Foulds, said that the models developed by the team confirmed Tegel's thoughts about important parameters, but he was impressed by the way the group attacked the problem and how the members insisted on ensuring that everything was accounted for in the problem solution.

Problem 3

Wind power is an important potential source of large amounts of renewable energy. Unlike conventional energy generation, the amount of energy produced cannot be specified in advance as it depends on the wind velocity which can vary significantly over short periods of time. This makes balancing supply and demand more difficult. An ability to predict the possible range of wind velocity for the next 5 minutes to the next 24 hours would assist in the scheduling and purchasing of power. Power supply is balanced with demand on a five-minute basis and bids for purchase of power become firm two hours ahead. The uncertainty due to large amounts of wind power on a power network is expected to make both balancing power supply and demand, and realistic bidding for supply, much more difficult.

Developing a solution

This MISG project looked at the prediction of wind velocity and associated power generation to determine how well these can be predicted. The Tararua wind farm supplied scaled wind and power data from their site, and meteorological data and predictions had been obtained for the three nearest cities.

An initial graphical analysis was undertaken to develop an understanding of the available data. This determined the periods for which data was available and how missing data had been coded. Significant differences were found in the data from the two sources. The data were then examined using several techniques.

The 'simple persistence' method, which assumes a constant wind velocity, is used as the basis to compare other methods. It was found that this method gives good results for prediction of short time periods, but loses accuracy as the prediction time increases.

Linear regression was used to develop simple prediction equations. These clearly showed a progressive loss of accuracy as the prediction time increased beyond about three hours.

The Kalman filter is a linear technique that progressively updates a prediction equation according to the error in the last predictions. An initial test of a Kalman filter was undertaken. This technique is considered to be promising as it has the potential to adapt to changing conditions.

Several neural network techniques were investigated. Neural networks provide a black box method that can conveniently develop predictions of complex responses behaviour. However, developing (training) a neural network requires much more computation than the linear methods above. The initial neural networks were able to some improvement over the persistence method. Specifically, a study by Zeke Chan of AUT indicated that ANNs reduced the average forecast error by 13% in a 4-hour forecast and 16% in a 12-hour forecast. Ray Hoare's Multi-Layer Perceptron (MLP) study showed that standard neural network software could be used to produce useful predictions.

An extension of networks due to Timothy Hong was also tested. This divided the dependent variables into regions using multiple fuzzy sets and trained a network for each region. Predictions were made by combining the neural network predictions according to the fuzzy set memberships. Again, improvements over the persistence method were demonstrated.

All the methods investigated potentially improve on the simple persistence method. However, none gave large improvements. According to EU experience, a combination of prediction approaches seems to be most promising. It is firmly believed that past data from one site cannot provide accurate longer-term prediction of wind, and data from other sites will be needed to improve such forecasts. Therefore, it is recommended that an individual model for each wind farm site be developed. Meteorology data is collected on a world-wide basis and, together with forecasting techniques, provides the information from other sites processed to provide local weather forecasts and thus has the potential to improve on the longer-term forecasts.

Problem 4

Solid Energy operates the two coal mines, Terrace and Spring Creek, on the West Coast of the South Island. They asked the MISG group to quantify the damage likely to occur in their mines due to a magnitude eight earthquake on the Alpine fault. The mine workings are typically 200–400 m deep and they are about 40 km distant from the Alpine Fault.

Developing a solution

First, the group investigated the wavelength and type of waves likely to be incident upon the mine workings. Using published data, it was determined that the most energetic wavelengths in the earthquake response spectrum were 200–500 m in length. Also, the group calculated that Rayleigh, or surface waves, decay to one per cent of their surface energies at a distance approximately 100 m below the surface. A survey paper in the literature indicated that, of 132 cases of earthquakes at mine sites, moderate or heavy damage rarely occurred below 100 m. This result fits nicely with the decay scale of the Rayleigh waves calculated by the MISG group. Hence, Rayleigh waves have no impact and the mine workings are subject to long S and P body-waves only.

Second, an empirical relationship from the literature was used to determine the peak acceleration of the waves at the mine workings, in terms of the earthquake magnitude and the distance from the fault. For the Terrace and Spring Creeks mines, peak accelerations were estimated to be 0.2 g, where g is the acceleration due to gravity. The literature suggests that severe damage occurs for accelerations greater than 0.5 g. Hence, it is likely that the Terrace and Spring Creeks mines would be subject to light damage only.

Third, the interaction of S body-waves and the mine roadway was considered numerically using a finite-element package. These roadways can be 500 m long, which is comparable to the wavelength, so the possibility of resonant interactions was investigated. The numerical results indicated that some slight amplification of the strain did occur, due to the presence of the roadway, but resonant amplification did not occur.

Finally, consideration of the energy released by a magnitude 8 earthquake on the Alpine Fault suggested that this may occur either as one event (as is usually assumed), or as a series of discrete events, analogous to domino collapse. The latter scenario could reduce the calculated damage, especially in the near field.

In summary, serious damage to the Terrace and Spring Creek mine workings, which are 200–400 m deep, is unlikely to occur as the result of a magnitude 8 earthquake. However, Rayleigh waves are likely to damage the mine portal, and damage to the surface portal seems a good area for future investigation.

Problem 5

As a Regional Council, Environment Canterbury is responsible for many aspects of environmental protection and sustainability. A major weed problem has been recognised in the form of wilding conifers spreading from existing plantations and shelterbelts. These wildings threaten native vegetation and important wildlife habitat, as well as impacting on pastoral farmland and the visual and recreational values of Canterbury landscapes. A recent Environment Canterbury survey mapped over 60 000 hectares of conifers, including both plantations and wildings. It is estimated that seed dispersal from these threatens a further one million hectares of land. Under the Regional Pest Management Strategy 2002, Environment Canterbury has received some funding for wilding conifer control, but this is limited relative to the scale of the problem. Thus, the control budget needs to be allocated strategically in order to achieve the best possible environmental outcomes for the dollars spent. The problem posed to the MISG centred on modelling wilding conifer spread, with the overall aim of setting priorities for sites for control operations.

Developing a solution

The study group focused efforts on three interrelated aspects. The first was to develop an understanding of the topographic and climatic drivers of short and long distance seed dispersal, in order to identify which existing conifer sites posed the greatest risk to the surrounding land. Fringe spread occurs when seed is released from a tree and is carried some horizontal distance by the wind, until it falls to the ground under the force of gravity. However, *Pinus* seeds will typically only spread about 100 m in this manner. To achieve the 8–10 km dispersal distances observed in invasive field situations, the group showed that the effective release height of the seeds had to be much greater than tree height. The literature suggests that thermal uplift may be a major mechanism for this height gain. However, thermal uplift seemed unlikely at the site for which we had data at MISG – the Mount Barker site, near Lake Coleridge in the Canterbury high country. Strong northwest winds are the norm when the temperature is high, so thermal uplift is probably rare. The group thought that Mount Barker itself was functioning as a launching ramp for seeds released from mature trees upwind of the hill. They could be carried by the wind up and over, to be effectively released at a height 200 m above the surrounding land. Even though the great majority of seeds would be dropped in the area of low pressure in the lee of the hill, some would continue on the airflow and could travel the 8 km distance on winds over 100 km/h. Why then are these long distance spread events so rare (for example, only one to three major events at Mount Barker in 100 years) if topographic uplift can occur so easily? Some initial calculations showed that wind at slower speeds would tend to go around, rather than over, the hill, so that the seeds may not obtain the required release height. To assess risk of spread from a site, the group recommends that topographic and climatic factors be analysed in order to estimate both the maximum possible spread distance and the likely frequency of long distance spread events.

The second area of effort involved modelling the dispersal of seed once it has been released. Several distributions are suggested in the literature for modelling the density of seed rain and the distances traveled. These models describe the high seed densities that fall out of the airstream close to the source, and the long tail of seed that travels the greater distances. It is the outermost edge of the tail that determines the invasion speed of the conifers. Thus, it is important to model the distance and seed rain density correctly for those seeds that travel the farthest, in order to predict the invasion speed correctly. The group worked with a set of data from Mount Barker, which gave distance-from-source for each tree in the down-wind tail of wilding conifers. Several models were fitted to the data, and the group found that a model first proposed by Okubo and Levin described the tail well. The assumptions and approximations made in this model must now be checked before it can be recommended as appropriate for studying wilding conifer spread.

Finally, the group assessed the effectiveness of a range of management options for controlling conifer spread. The analysis was carried out by first developing a pragmatic model of invasion as a series of discrete steps occurring in a down-wind direction. The group defined a set of possible transitions from young to old, and scattered to dense trees, and assigned probabilities to these transitions. This enabled a computer simulation of year-on-year invasion to be developed. Knowing that there was not sufficient budget to remove all trees, the task was to find the management strategy that provided the best control of invaded area. A range of possible management strategies was defined, such as always targeting the largest patches of trees for removal, or always targeting the oldest. These were also simulated using the chosen management strategy of removing particular patches of trees each year and allowing the remainder to continue growing and spreading. Some strategies, such as targeting the oldest trees, did not provide good control. Targeting the youngest (which would equate to the outermost edges of the tail of wilding conifers) worked much better. The number of trees cut each year could also be varied in this simulation. The next steps would be to bring in a more detailed model of spread (relatively simple assumptions were used during this initial development), along with dollar-value costs for each of the control strategies. This simulation has the potential to provide a valuable framework for predicting and visualising the effect of various control strategies.

The group at the MISG has increased our understanding of topographic and climatic drivers of wilding conifer dispersal distances and event frequency. A more realistic model of seed rain density has been tested, supporting more accurate predictions of invasion speed. These developments are important for site risk assessment. A framework has been developed for modelling conifer invasion in space and time, and for predicting the level of control expected from various management strategies.

Problem 6

Compac Sorting Equipment makes very nifty machines for sorting fruit by weight, diameter, colour, density, blemish or even shape. Compac sought solutions to two closely related problems: the boxing problem and the bagging problem. The boxing problem requires graded fruit to be assigned to outlets where boxes are filled with a specified number of fruit to a minimum weight (and a specified tolerance for under-weights). The aim is to maximise the number of boxes packed. The decision must be made after all information is known, but before the fruit passes the first outlet – a few seconds in total. Further, information about fruit already packed in a given box is incomplete (we don't know exactly which fruit ended up in a given box). The bagging problem requires bags to be filled to a minimum weight – no tolerance for under-weights, and no constraints on the number of fruit per bag. In this case complete information is available on fruit already assigned to a bag. Again, the aim is to maximise the number of bags packed.

Developing a solution

The MISG team was able to provide a 'close to optimal' solution to the boxing problem for the simplest information scenario where an irrevocable decision is made for each fruit in turn, and no memory of previous assignments is retained. This information scenario is the least demanding of real time measurement for Compac and is also the simplest to analyse and optimise. Basically, it is an attempt to improve on an old idea already implemented by Compac – 'static cut points'. Cut points define the category (and hence the outlet) to which a fruit will be assigned. Potentially, the value of the fruit may be different for different categories. The cut point optimisation problem was formulated with the objective of revenue maximisation. The determination of globally optimal solutions is non-trivial, but some approximations and assumptions yielded a tractable solution method. We are confident that the solutions given by this approach won't be substantially worse than those from any other approach. Hence, we claim a 'close to optimal' result. Compac believes that there is value in adapting the choice of the cut points to the distribution of the incoming fruit. The solution method proposed does depend on this distribution, and it can be re-run if the distribution changes significantly. We were able to provide software to solve the cut-point optimisation and a simulation of the resulting decision system. The simulation results compared favourably with Compac's current approach.

The team investigated a range of approaches to realise the potential benefits of richer information scenarios. Each method assumed some knowledge of previous assignments to an outlet. They also exploited the fact that the system has a period of time between when all information about the fruit is known and when it must commit to a decision. Some tens of fruit can therefore be considered together. These approaches use the fact that weight allowances of fruit categories overlap. An 18 kg, 100-fruit box has an average weight of 180 g per fruit. But, if we aim for a target weight of 180 g, the variance in individual weights means that we will often get underweight boxes. The proposed methods choose target weights sufficiently above the minimum target (180 g in this case) using the variance for weight of fruit already sent to the outlet so that it is unlikely that a box will be underweight. The trick then is to minimise the variance. One of the algorithms looked for good combinations of pairs of fruit (even pairs of pears!).

It was not possible to fully quantify the improvements that the use of this extra information would yield, but a range of algorithms was developed that can be investigated further. We looked at the bagging problem in two ways. The first concentrated on the physical aspects of the problem. The physical constraints have a very large impact on the problem. For example, fruit from a near-side lane arrives faster than far-side lanes, so if we are just finishing off a bag, near-side fruit is much preferred. Restrictions in the number of fruit that can be allowed to cycle must also be observed. A Matlab model was created that simulates some of these physical restrictions, and has been made available to Compac. An algorithm for choosing the fruit based on 'preference zones' was developed, where bags close to finishing were allowed to choose fruit from their 'most-preferred' zone before other bags got to pick over the remaining fruit. Unfortunately, we didn't have enough time to run this algorithm through the simulation.

A second approach concentrated on trying to find the best three or four fruit to finish off a bag. A method was presented that is feasible for real time implementation, both in terms of the information (measurements) and computation required. Simulations suggested that this algorithm significantly out-performs the current, simplistic approach of first-in-first-out. It currently assumes pre-graded fruit, but could be made more generic – allowing fruit that can be classed into more than one grade.

Efficient contracts for carbon credits from reforestation projects

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Introduction

The Kyoto Protocol creates the potential for rewards for carbon sequestration in both developed and developing countries. In developed countries that have ratified the Kyoto Protocol such as New Zealand, credits could be used as part of domestic regulation to encourage carbon sequestration in new forests and hence meet international commitments. A seller produces credits by afforesting/reforesting and a buyer uses those credits to comply with domestic or international commitments.

Storage and sequestration contracts are more complex than many emission reduction contracts because carbon stored in forests is potentially temporary. A raging debate has argued about how international rules should deal with this.[1] In the context of the Kyoto Protocol, land-use related credits are tradable one-for-one with credits from reduced fossil fuel emissions. Sequestration of carbon that creates internationally tradable credits needs to have the same atmospheric effect in the same time period as the emission reductions that the credits would replace. In this paper I assume that sinks are treated as temporary stores of carbon and that either the seller or buyer is held liable for paying back any credits accrued if the sink is destroyed. This follows Chomitz (1998 and 2000), Colombia (2000), Kerr & Leining (2000), Leining & Kerr (2001), Marland et al. (2001) and Kerr (2001), among others.

Credits created under domestic regulations need to have environmental integrity and fit broadly within the international rules for monitoring and reporting. Domestic governments can have simpler rules for example, for monitoring than international ones but have to take responsibility for the impact of any credit trades on their ability to meet international obligations. However, this still leaves lots of freedom to choose. Understanding the limitations and flexibility available in contract design and the tradeoffs between different approaches is clearly useful for traders. It is also useful to those who are designing regulations. They need to understand the value of contract flexibility so that they do not unnecessarily constrain the forms of contract available. Brokers and market makers could design standard contracts and make information available that helps traders understand how best to design a contract to meet their needs.

The purpose of this paper is first to describe carbon sequestration or 'sink' contracts that meet environmental, regulatory and economic constraints.[2] I then characterise the performance of these contracts and show how the best choice depends on the characteristics of the parties involved.

Assumptions about the regulation under which the contracts operate

I assume an annual reporting and rewarding process. This is for convenience and is not essential. The greenhouse gas GHG benefits from land-use change can be lost or reversed over time, unlike the GHG benefits from emissions reductions in other sectors. I assume that all land-use related carbon storage is temporary and is rewarded accordingly through tradable credits. Credits are given each year for sequestration and debits are applied each year for loss of carbon through harvesting or deforestation.[3] Permanent forests are simply a special case.

I assume that the 'baseline' carbon (i.e. how much would have been sequestered or stored without the policy) is known, or at least a baseline is set. Any carbon sequestration above

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[1] Papers that propose and discuss issues relating to the appropriate international rules include Dobes et al. (1998), Fearnside et al. (2000), MacLaren (2000), Marland et al. (1997), Meinshausen & Hare (2000), Moura Costa & Wilson (2000), Schwarze & Niles (2000), Schlamadinger & Marland (2000), Sedjo & Toman (2001), Sedjo et al. (2001) and Van Kooten et al. (1997).

[2] Similar issues are discussed in Sedjo & Marland (2003), with more emphasis on international trading.

[3] This is equivalent to modelling sequestration in Kyoto forests under Article 3.3 of the Kyoto Protocol.

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this is 'additional' and is eligible for reward. I assume that land-use and carbon monitoring is the same across all contract forms and in the first part of the analysis is risk-free from the point of view of buyers and sellers (i.e. once the project starts, the monitoring rules are fixed and once carbon is monitored, the number of credits is set and will not change).

Traders could be individuals, companies or countries. I assume, however, that they are both 'small' enough that they cannot affect the regulatory conditions relating to trade and that they are price takers in the international market.

Contract options and their implications

In this section I define a few basic contract forms and the key parameters that cause them to differ. I discuss the limitations the market places on how these contracts work – chiefly that both buyer and seller must be willing to agree to the terms. I then compare the contracts under a range of situations and with different characteristics of buyers and sellers and show what types of situations might call for different contract forms. I illustrate each of these with a concrete example of a regeneration project on 100 ha of land. I assume that there is no risk and that future credit prices and levels of actual sequestration are known with certainty.

Contract 1: Sell credits as you go – seller liable for credit repayment

The simplest contract is one where credits are sold as they are created and then, if the forest is cleared, all credits are repaid by the landowner. Each year, this contract will be worth the current credit price times the new quantity of carbon dioxide.[4] In the final year it will bear a liability equal to the current credit price multiplied by the accumulated CO_2.

Different contract designs will provide payments at different points in time. To compare contracts we need to translate payments at different points in time into a common 'currency'. When does the timing of payments matter? First, the buyer and seller might have different access to credit. Investors with their own money are in a different situation from people who are already in debt. This means they face different interest rates. Second, people and groups may simply have differences in time preference, or differences in when they prefer to enjoy benefits. Some people like to have their returns quickly, while others are willing to wait and may even enjoy the anticipation of future benefits. This partly depends on current versus future income as well as age and possibly culture. It can be thought of in terms of how patient the actor is. The interest rate and underlying patience are summarised in the 'discount rate', which is an indicator of how much an actor would need to be paid to wait an extra year to receive payment.

If the landowner is more patient than the buyer lower discount rate then they will get more value from the project if they agree to receive payments later rather than earlier in exchange for higher total payments. If they are less patient higher discount rate; for example, if they are in debt or face credit constraints they would get more value with an up-front payment even if it is lower. I define the discount rate for the seller as d per year.

[4] Although forests sequester carbon, Kyoto is designated in terms of carbon dioxide (CO_2) equivalents so the international price most readers will be familiar with will be the CO_2 price. 1 tonne C = 3.65 tonnes CO_2.

p_t is the price of CO_2 credits on the market at time t. An active market determines this. No buyer will pay more than this because they could buy credits elsewhere for this price. No seller should accept less for risk-free credits because they could sell the credits elsewhere. q_t is the quantity of new sequestration available to be sold at time t. T is the length of the project. If it is less than infinite, then q_T, the 'new sequestration' in the last period, is negative and the credits will need to be bought back. This would apply either if the land is cleared and converted to a non-forest use, or if monitoring stops so the regulator cannot assess carbon storage or sequestration.

V is the present value to the seller of the revenue stream from the project. A stream of credits sold each year and repaid by the seller at T is worth V_1 as follows:

$$V_1 = \sum_{t=0}^{t=T} \frac{1}{(1+d)^t} p_t q_t \qquad 1$$

If I define p_0 as the initial carbon price and i_t as the rate of increase in carbon dioxide prices over the period of the contract, I can rewrite this as:

$$V_1 = \sum_{t=0}^{t=T-1} \frac{(1+i)^t}{(1+d)^t} p_0 q_t - \frac{(1+i)^T}{(1+d)^T} p_0 \sum_{t=0}^{t=T-1} q_t \qquad 2$$

This makes the final repayment of credits, the final term, explicit.

Basic case for project examples

In the base case we assume the project covers 100 ha, starts in 2003 and lasts for 10 years. Each year 6.2 tonnes of CO_2 accumulates per ha. Thus q_t $t < T = 620$. In the base case, the carbon dioxide price, p_t, is $10 per tonne; the seller's discount rate, d, is 10% and the buyer or market discount rate[5], r, is 10%. The credit inflation rate, i, = 5%.

In the base case, the project would be worth $9,949 in 2003 under this form of contract. The contract has positive value even though the net sequestration over the whole project is zero, because carbon prices rise at a lower rate than the seller.s discount rate, so the present value of the final liability is not too high. The lower is i and the higher is d, the more valuable the project is.

The project is worth doing if:

$$V_1 > AR + Cost \qquad 3$$

where AR = present value of alternative return on the land over the period, and Cost = direct costs of setting up and running the project.[6] All contracts will be worth more if the credit price is higher, if the carbon is sequestered faster, and/or if the costs of setting up and running the project are a smaller proportion of the total value(e.g. because the project is larger and the costs are fixed). Projects will also be more valuable on land that has fewer alternative uses.

[5] I assume that the buyer's discount rate will be equal to the market real interest rate because all buyers will pay the same for a rental contract in a liquid market.

[6] This would include the present value of monitoring, compliance and maintenance costs.

Contract 2: Rental - buyer liable for credit repayment

An alternative contract form is a lease or rental contract where the buyer pays the seller a certain amount each year as long as the credits are protected. The seller maintains the right to have the credits returned at any time, subject to contractual restrictions. In contrast to the sale contract, the seller maintains ownership of the credits at all times. This means that they can sell them or stop the project and not have to pay them back when the contract ends.

The buyer will use the credits for compliance purposes and will buy credits or rent credits from someone else when they can no longer use those provided through the contract.[7] Under this contract the seller landowner has no deforestation liability.

The buyer faces a decision about whether to buy or rent credits. The amount the buyer is willing to pay to rent will depend on their discount rate and the rate at which they expect credit prices to rise. If the rental contract were infinite, the price rise would not matter because they would never have to pay the credits back. In a finite or potentially finite contract, however, the buyer will be concerned that at some point they will be unable to rent the credits and will have to buy them at the then-current market price.

The buyer avoids the cost of the full outlay on the credits and so saves an amount rP_t on each credit, in each year, where p_t is the price he would have had to pay for them in the year they were created. That is, the rental price adjusts each year, even on existing credits. r is the buyer's discount rate. However, each year he accumulates a larger potential obligation to repay if the value of credits rises. This obligation increases by iP_t each year, where i is the expected rate of inflation in credit prices. Thus, his net gain from renting rather than buying immediately is $r\text{-}iP_t$. This is how much he will be willing to pay each year for each credit he holds (i.e. the cumulative number), not only the additional credits that year. If i were high or his discount rate low, he would not be willing to rent.

The value of a rental contract to the seller is the present value of all the future rental payments.[8] The seller does not have to buy back the credits at the end so there is no final term equivalent to that in Contract 1. The value is:

$$V_2 = \sum_{t=0}^{T}[(r-i)\frac{(1+i)^{t-1}}{(1+d)^t}\,p_0\sum_{s=0}^{t}q_s] \qquad 4$$

If the buyer and seller have the same discount rate (i.e. $r = d$), then $V_2 = V_1$.[9] The pattern of cashflow is different but the total value of the contract is the same.

Renting is most valuable when people believe that technological advances will make climate change mitigation relatively cheap in the medium term and hence make carbon prices fall. If we solve the problems of the hydrogen economy in the next, say, 50 years, carbon prices may fall close to zero even though they might be high in the interim period. Many models predict this sort of price path. Prices would also fall to zero if the international agreement collapsed or we found that climate change was not a problem and halted our efforts. Sequestration is most valuable relative to emission reductions in these situations because it offers the opportunity to delay emission reductions while making short term atmospheric gains.

In both contracts 1 and 2 and all other contracts, if $i = r = d$ and the contract length is finite, the project has a value of zero. There is no point in buying time through temporary sinks when the credit price goes up as fast as your value of money. In contrast, a contract that lasts in perpetuity still has a positive value because the credits will never have to be paid back so the credit inflation rate does not hurt.

Because some of the payments are delayed, rental contracts are more valuable the more patient the seller and the less patient the buyer. For example, if the seller is more patient than the buyer seller has discount rate $r = 5\%$ rather than 10% the value of this contract rises from \$9,949 to \$13,286. In contrast, if the seller is less patient, the contract value will shrink. A patient seller would not accept a finite sell-credits-as-you-go contract because it would be worth nothing to them - the liability would grow at the same rate as they gain credits - while an impatient seller would much prefer the sell-as-you-go contract to the rental see Table 1.

Contract 3: Up-front payment

A third popular form of contract is where the seller is paid an up-front sum for a project of a defined length. The buyer might be willing to pay the present value of all the credits expected to be created in the future, even though they will not be able to sell them until later.[10] The seller is responsible for paying the credits back if they cut the forest. The value of an up-front contract is:

$$V_3 = \sum_{t=0}^{t=T-1}\frac{(1+i)^t}{(1+r)^t}\,p_0 q_t - \frac{(1+i)^T}{(1+d)^T}\,p_0\sum_{t=0}^{t=T-1}q_t \qquad 5$$

This will be an attractive contract form if the seller is impatient and wants to be paid early (i.e. the value of d is high relative to r). If the buyer and seller are identical, the value of this contract V_3 is equal to V_1 or \$9,949.

Figure 1 shows the cashflow implications of each of the three contracts: Pay-as-you-go (PAYG), rental and up-front payment. Although each has the same present value under our assumptions, clearly they have very different impacts through time.

Table 1 shows that in the contracts where the seller receives funds earlier and has to pay back credits, 1 and 3, the more impatient the seller is, the higher the value is. A more impatient seller is less concerned about future liabilities and so finds these contracts more attractive other things being equal. In contrast, if the seller is more patient, the rental contract becomes more favourable.[11]

[7] A possibly useful analogy is that of someone deciding to rent or buy a house. The buyer needs a 'house' to offset its emissions in the first year. If it rents the house, that will satisfy its needs temporarily, but when the seller no longer wants to rent out the house the buyer will need to find another house.

[8] The rental payments are modelled as though they are made at the end of each year. This is simply because I am modelling in discrete time periods.

[9] See Appendix A in Kerr (2003) for proof.

[10] They may be able to sell on futures markets if they exist.

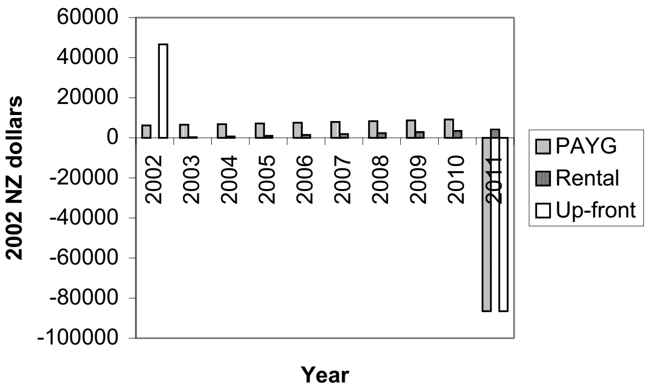

Figure 1. Seller/landowner cashflow for each contract (in 2002 NZ dollars).

ity. Each contract is consistent with credits provided by government each period and liability owed to the government on harvest. Thus, their environmental effects are identical. The contracts are structured so that in our base case, where the buyer and seller are identical, the present value of the contracts how much the contract is worth at the beginning is identical. All contracts are more valuable if the price of carbon is higher, if the carbon yield per year is higher, or if the project covers a greater land area. All finite contracts have zero value if the rate of credit inflation, i, is greater than or equal to the buyer's and seller's discount rates, r and d.

The contracts have very different cash-flow implications, however, so that if the buyer and seller have different attitudes to the timing of payments and to the liability 10 years away, the contract choice is important. The key factor in choosing a contract form is the 'patience' of the buyer relative to the seller.

Table 1. Value of different contract forms to the landowner/seller of credits.

	Sell as created 1	Rental/ lease 2	Up-front payment 3	Perpetuity (credits sold as created) 4
Base case: $d = r > i$	9,949	9,949	9,949	129,000
Higher future prices: $d = r = i$ *	0	0	0	372,000
Impatient seller: d = 15%	15,251	7,625	23,398	71,000
Patient seller: d = 5%	0	13,286	−11,260	434,000

* Inflation assumed to be 10% for 50 years, then zero. This is probably a high estimate of future carbon prices.

If credit prices rise fast, the 'in perpetuity' contract becomes the only favourable contract. There is little or no value from temporary sequestration. The 'in perpetuity' option would not have to be chosen in advance. Extension of any of the other contracts or translation into an 'in perpetuity' contract would become more attractive over time if actors see that credit prices are continuing to rise. The 'in perpetuity' contract will be more attractive to patient than impatient sellers because patient sellers value the payments in the distant future and are concerned about future liability.

Conclusions

Encouraging additional carbon sequestration through reforestation can probably be most effectively done by providing payments by allocating credits for new forests. These payments/credits need to be matched by liability if the forest is harvested. This paper addresses only one aspect of the design of such policies, the optimal design of the contract between the credit buyer (e.g. fossil fuel emitter) and seller (landowner when there is no uncertainty).

This paper has illustrated three basic forms of contract where a buyer pays a seller for sequestration and one bears the liability. If the buyer has greater access to cheap credit and greater ability to wait for income, it is better for the contract to be biased toward payments up front. If the seller is more 'patient', the contract should spread the payments out further. Curiously, the less patient actor also should take responsibility to repay the credits when the contract ends because they heavily discount the future liability.

Potential forest developers are a very heterogeneous group that includes large corporates and individual farm foresters. Their attitudes to cash flow are likely to differ greatly. Our results suggest that, in this situation, flexibility in contract design is probably very important. This flexibility could be achieved by having a flexible government policy that allows land-owners to choose how they relate to government. Alternatively, if the government policy offers only the pay-as-you-go contract, flexibility can be created by ensuring that a private market develops. The private market players would sell credits on the forward market (i.e. sell them before they are created) to create the up-front contract, or buy them in advance for the end of the contract period so that the liability is paid in advance, thus creating a cashflow equivalent to the rental contract.

[11] I have not modelled a contract with rental payments all made up front but with the buyer still bearing the liability. The impatient buyer would prefer higher payments in exchange for the liability, while the patient seller would prefer the stream of somewhat higher rental payments and buyer liability. Thus, it is dominated by other contracts. I have also not modelled a contract where the seller is paid at the end of the contract. This will have the opposite effects and attractiveness to an up-front contract.

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Dr Hooligan MacMargaretson and experiences on a PBRF panel

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I have just spent four days in Wellington on the Biological Sciences Panel of the Performance Based Research Fund (PBRF). The panel of 18 people evaluated over 660 forms, each form representing a real live person from the Tertiary Education sector. And I am still sane, and even a little wiser! At the end we had every one of these forms (surrogate for human researchers) categorised into levels as follows:

- Level I, those with restricted or limited research activity (step R)
- Level II, having a good research platform (step C)
- Level III, as for Level II but with a national research profile (step B)
- Level IV, having an international research profile (step A).

So far, so good! The bad news is that a sizeable group of the 660+ researchers will be disappointed by their ranking from the 'idiot no-good panel members'– the real research people being judged by the no-good layabout managers. Okay, a few will be ranked higher by the panel than by their own Institution; conversely, they will recognise the panel members as really intelligent, rising above the dirty politics of their own Institution.

Keeping to the evidence

The good news (perhaps) is that the researchers weren't evaluated at all, only their forms were evaluated. If the information wasn't there, then it wasn't considered (even though some panel members knew additional information that would be helpful). In quite a few cases it was recognised that a researcher had tremendous potential, but only the evidence on the EPs (Evidence Portfolios) was used. Disappointed researchers will take it personally, but the ranking was based on the forms and was not personal.

This was perhaps the real strength of the exercise; the panel kept to the evidence presented by the researcher (maybe the researcher had had a bit of mentoring from within their institution, but clearly not always). The time period (1997–2002) was also kept to strictly. Indeed, prior to the meeting the support staff at the Tertiary Education Commission (TEC) had already audited the four main nominated research items for every individual. How they managed such a large task is beyond me! We were required to check at least 10% of the main nominated items. One reference I downloaded from the Web had four (repeat four) errors in the title, list of authors, year, issue, and page numbers! Yes, it had to have some carry-over in evaluating the research ability of the forms (aka researchers) that we were checking. In that particular case, I simply put the article aside and read it the next day – hoping the frustration at the researchers' incompetence with the details of their own publication had worn off.

Feedback

Perhaps my biggest concern is that there needs to be more feedback to the 'research entities' that filled in the forms. This time around, major funding change will not result from the PBRF evaluation, and clearly some researchers had not taken the 'exercise' too seriously. However, re-allocation will increase annually and become significant in three years' time. There will be increasing pressures from institutions for all their staff to get the highest possible grading. At this point, I will introduce an example, the quite well-known researcher, Dr Hooligan MacMargaretson. We can follow examples of how the panel reasoned about some of the forms they received and you will see that our friend Hooligan caused quite a few anxious moments.

In one case a young researcher was evaluated as Level I, but a panel member pointed out that Dr MacMargaretson was first author in a *Science* paper in 2003. This was outside the 1997–2002 time period, so could not be used. But the response of panel members was, 'Wow, this person will really take off for the next time around' – but it didn't affect the grading this round for 1997–2002. Indeed, seeing the potential of some of the younger researchers was one of the few actual pleasures of the exercise. This emphasises again that it was the 'forms', not the people, which were being evaluated. Hooligan might have

Scientific Director, Professor David Penny, has held office as President of the Society of Molecular Biology and Evolution an international society (currently 891 members) which publishes the high impact journal *Molecular Biology and Evolution* (*MBE*) with 525 institutional subscribers. One of Professor Penny's achievements was to initiate the process that led to *MBE* becoming the first scientific journal to have all its previous and current publications available on the world wide web. He has also been President of the New Zealand Association of Scientists. During his term he initiated and organised funding for the annual Science Communicator's Award. In 1998 Professor Penny was chairman of the External Review Committee of the Institute of Statistical Mathematics (ISM) of Japan, and in 2001 was a member of the committee reviewing priorities of the Causes of Biodiversity research programme of the DFG (German Scientific Research Funding Agency.) In 2000 Prof Penny was awarded the Marsden Medal in recognition of the contributions he has made to science in New Zealand. He is a Fellow of the Royal Society of New Zealand.

been put in Level 1 this time around, but we would expect to see a good leap in the next round in three years. In quite a few similar cases it was obvious that younger people were establishing a good basis for an excellent research career.

Choice of papers

The selection of four key research outputs was important. The main thing this achieved was to focus on the quality of the research, making it easier to evaluate younger researchers (who did not necessarily have the same bulk of papers as more established figures). The selection of just four publications was clearly a problem for quite a few researchers, and in some cases they certainly did not get it right. In a few cases, one of the four (a Nominated Research Output) was ruled ineligible by the TEC staff (usually because of uncertainty over publication dates – in such cases the employing organisation had been asked to check). This could, for example, leave a researcher with only three (not four) main items. The response of the panel was to select 'mentally' the best from the remaining research listed and treat it as if it was nominated. Thus, the panel could be helpful towards the researchers, but only if the information had been included in the first place. It is still necessary to fill in the forms as accurately as possible.

There was an ongoing problem about which were the best publications to choose. Panel members, following the guidelines, were a bit negative toward general reviews included in the primary category of Research Output – unless it was clear that the review was introducing novel ideas or a synthesis of the field. Otherwise, reviews contributed better to 'Peer Esteem' and to 'Contribution to the Research Environment'. However, by looking at Table 1 you see that the score on the Research Output category carried by far the most weight. It was also important to fill in the researcher's contribution to a publication; this helped give an overview of research strengths. There was a little light relief to see whether different researchers contributing to the same publication contradicted themselves with respect to 'their contribution'. But there wasn't time for much of that, and our panel did not detect any significant cases. The very youngest researchers (such as new postdocs) were hard to evaluate (they might have a thesis and two publications), but this seemed a bit like 'double dipping' if the papers derived from the thesis. Four papers seemed considerably better than three papers and a thesis. If the papers were not from the thesis, this was important to state, and there was space on the form for this.

The panel appeared to take no notice of academic status or of institution. A few research technicians were on the list. In one case a panel member noted that one 'form' seemed to represent a researcher who did not have a PhD. The response was quick. But if 'x' (couldn't be our friend Dr Hoolie this time) was first author of paper in the journal *Molecular Skulduggery*, and *Molecular Skulduggery* is a good journal, then ''x' is certainly contributing good research, PhD or not. Conversely, ageing professors, overloaded by administrivia, were scrutinised carefully to see that they were still research-active. There was no value judgement here – administrivia is a fact of life and somebody has to do it. It was noted, in a few cases, that most publications were earlier in the time period considered (1997–2002), but the exercise was neutral to early or late in this time.

New Zealand journals

The position of journals published in New Zealand was a difficulty. The subjects covered by our panel included laboratory-based work (almost exclusively published overseas), to ecol-

Table 1. Converting scores from 'Evidence Portfolios' (EP) to 'Research Level'.

	RO Score							
Combined CRE & PE score	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0	0	70	140	210	280	350	420	490
1	15	85	155	225	295	365	435	505
2	30	100	170	240	310	380	450	520
3	45	115	185	255	325	395	465	535
4	60	130	200	270	340	410	480	550
5	75	145	215	285	355	425	495	565
6	90	160	230	300	370	440	510	580
7	105	175	245	315	385	455	525	595
8	120	190	260	330	400	470	540	610
9	135	205	275	345	415	485	555	625
10	150	220	290	360	430	500	570	640
11	165	235	305	375	445	515	585	655
12	180	250	320	390	460	530	600	670
13	195	265	335	405	475	545	615	685
14	210	280	350	420	490	560	630	700
	I		**II**		**III**			**IV**

‡ ***Note: A Research Output (RO) score of at least 2 was required for Research Level II, even if the total weighted score is 200 or greater. PE is 'Peer Esteem', CRE the 'Contribution to Research Environment'***

ogy and evolution (with a mixture of laboratory and field studies, again mainly published overseas), and then to applied work in agriculture, horticulture and forestry (much of it published in New Zealand). The composition of the panel was balanced, but it took at least a full day or so for the laboratory-based panel members to adjust to the different constraints on the more applied sector. Publication in New Zealand was often to make the work available to the main users (that is, New Zealanders). But how could the panel tell if the research really was world-class (as required for the higher Levels)? If some papers were published in the best overseas journals, then this gave a benchmark for quality, and it was easier to give a higher ranking to the remaining New Zealand publications.

Peer esteem

The Peer Esteem and Contribution to the Research Environment were the least well completed parts of the forms. Perhaps this is not surprising; we are all used to filling in our publications in grant applications and yearly reports. But blowing our own trumpets at what others might think of us, or what we have contributed generally, is not our forte. But the scoring system was relentless (see Table 1 again). If our dear friend Hooligan had done some brilliant research that was evaluated as a 5 (see Table 1) – but had not filled in these two sections, then the overall level just had to be Level II. Just filling in the form completely would have moved them up one level, and earned their institution three times the funding for research. Oh well, next time around maybe! In the meantime they may have some fast-talking to do as to why their level was lower than expected and why they are not earning as much research income as expected.

All the time, potential conflict of interests were monitored carefully. Obviously, for the major conflicts (those involving a panel member) they left the room before any discussion started. But for more normal ones, like being in the same department, the standard allowed the member to stay in the room, but not being allowed to say anything, even if asked. However, some Heads of Departments just preferred to leave the room if it involved anyone with their department. 'I don't want to have to bite my lip to stop me defending someone in my department', was one response.

Towards the end there was the opportunity to have an 'holistic' look at anyone a panel member thought might have been 'underdone' (wow, two lots of jargon at once!). But still the information on the form was paramount, the panel may have overlooked something - that was okay and could be looked at again. But, if the information wasn't there it couldn't be used – if young Hoolie hadn't included it, there was nothing the panel could do. The final step was to see the ranking each Institution had given their own researchers, and this picked out two significant anomalies (out of the 662). On the whole, the Institutions gave a higher ranking than the panel. In quite a few cases this is likely to be because the institutions saw the potential of the researcher, rather than current achievement up to the previous year. In that case, the Institutions had better ensure that the researchers have the time and facilities to achieve that potential!

Why the new system?

Although the previous section is on the activities of the panel, as a separate issue it is appropriate to consider the underlying reasons for the whole Performance Based Research Funding (PBRF). Just over a decade ago a disastrous decision was made to fund universities (oops, wash your mouth out! – I meant to say, Tertiary Education Organisations, TEOs) on the basis of teaching alone. That is, research funds were included with the money allocated for teaching. This was treating the TEOs strictly as an airline; 'bums on seats' was the name of the game. In fact, the EFTSs (Equivalent Full-Time Students) didn't even have to attend lectures or labs. All they had to do was enrol, pay their fees, collect their tertiary allowance, and do anything they liked. The government contribution still came in. I have seen examination results for some subjects where a large group of students apparently never turned up to lectures – nor handed in any work. But the institutions still received the government contribution for both teaching and for research. Utterly absurd!

The effect was disastrous for the university (oops again, TEO) system. The money for research transferred out from the established research areas (including science and applied science areas) into other areas, some of which did little research (or scholarship). This was no way to fund universities aiming at international comparability. At the same time institutions distorted their academic requirements to help trap EFTs (no longer students, humans or people) into their own institutions. For example, the idea of a common intermediate course for students in, say, biological sciences, disappeared. Institutions appeared not to care about 'students' and their education. If they could insist students had to do the Intermediate year at their institution, then the EFTSs might be trapped there. Next year they didn't have the prerequisites to swap to a different professional major at another university.

Student-centred education

When I started lecturing in the New Zealand system the Intermediate year was seen as empowering students to diversify into a wide range of options in the second year, and at a range of universities. It was a student-centred system. Now, if we can get the bums associated with the EFTSs to our institution, and give them an Intermediate that is only suitable for our Professional Schools, then we (the Institution) are ahead on the numbers game – and with that went research funding. Stuff what the EFTSs (aka students) wanted. Combine this with a system that overpaid universities for first-year students, but did not fund them enough for later years, then institutions needed first year EFTSs to subsidise later years in the course. Subjects such as geology, that lacked large first-year courses, really suffered. Basically, New Zealand universities have had 30 years of inadequate leadership from the top.

Thus, in principle, I will argue that the new system (where research funds go into those areas of active research) is a definite improvement. It may not necessarily be the best. I recently stopped in Halifax in Nova Scotia *en route* to Europe, and found the Canadians going through their five-yearly exercise for research funding. They went through a similar exercise to PBRF, requiring demonstrating their research activity and output over the previous five years. But, on the basis of this process, the researchers I met expected to receive around $30,000–40,000 per annum (even up to a $100,000) for the next five years as 'their' research funding – not filtered through the University hierarchy to use as it saw fit – the funding effectively went to the researchers.

Funding rewards researchers

There will be a conflict here between the interests of the researchers and those of the institution. Under the Canadian system, all active researchers have a guaranteed base funding. Great! But institutions in Kiwiland may argue for more ‘flexibility’ (aka control) for building up new areas, or getting selected people to reach targeted goals. It really is important that the bulk of the PBRF research funding go to the researchers themselves. So, although our new system is a vast improvement over the previous one, we should not be complacent – research funding is still extremely difficult for many good researchers to find. The Marsden Fund works well for a small group of researchers, but is certainly not intended as base funding for institutions. Until recently the FRST system looked almost exactly the same as the old Head Office of DSIR, with complete centralisation. It doesn’t see its role as either research excellence, or for the large majority of researchers. The PBRF seems the best chance for the majority to meet their research needs. Watch the forms improve next time around!

Almost certainly someone will complain that the new funding of research will lead to ‘moral decay and turpitude’ through a neglect of undergraduate teaching. Personally, I do not accept the view that there is a trade off between research and excellence in undergraduate teaching. My experience as a graduate student at Yale was that people were invited to give lectures to first-year biology – but if at the end of the lecture they did not get enough applause from the students, they were not invited back next year. Then, when I have been let out on parole (aka sabbatical), and worked at Oxford and Cambridge Universities, I found real interest and concern in teaching. Excellence in teaching and research can go together. To suggest otherwise really is whinging; a real speciality of academics. The bulk of the money coming into universities will still be for teaching – ignore it at your peril! However, the experience in the UK is that pupils completing High School take note of the research standing of the different universities.

Enough of my views! Back to the PBRF panel experiences! It was a positive experience (even if a damned nuisance from the time it took up). This time around was a bit of a practice in the sense that it is not making major shifts in funding. Clearly, everyone needs to be more focused in future. The new system focuses on quality researchers, not the centralised management-controlled research of the FRST system. New Zealand now has two systems competing head on: researcher drive versus tight centralised control. I foresee the researcher-driven system as an opportunity for a real improvement in scholarship and research.

Corrigenda: *New Zealand Science Review* 60 (4), 2003

Owing to a software malfunction during printing, a typographical error occurred in the article ‘Understanding the past – discover a future’ by Charles Daugherty, *New Zealand Science Review* 60 (4): 141–42, and several errors occurred in the article ‘New Zealand and Bellingshausen: The Russian Antarctic Expedition 1819–1821’ by Garry Tee, *New Zealand Science Review* 60 (4): 143–144.

In the text of Professor Daugherty’s article, the malfunction resulted in the deletion of letter ü from Albert Günther’s name. The corrected reference for Albert Günther’s 1867 work cited by Professor Daugherty is as follows:

Günther, A. 1867. Contribution to the anatomy of *Hatteria* (Rhynchocepalus, Owen). *Philosophical Transactions of the Royal Society (London) 157*: 595–629.

In the text of Professor Tee’s article, not only was the letter ü deleted, but also quotation marks were deleted in several places, rendering it unclear where the text was his own words and where it was quoted. We have therefore reprinted his article on pages 35–36 in its entirety as it appeared in *The Wind*, No. 80, May 2003, p.6.

Editor

Report

A new Policy Unit for the Royal Society of New Zealand

The new Policy Unit

The Royal Society of New Zealand (RSNZ) has recently appointed two policy analysts to further develop the policy role of the Society. The Policy Unit comprises Dr Kathleen Logan and Dr Jez Weston, both recently practising scientists, whose skills and interests are complementary.

Prior to arriving at the RSNZ in Wellington, Dr Logan was involved in biotechnology research in Dunedin, having previously worked on two post-doctoral contracts at AgResearch Wallaceville. The move to policy work was not pre-meditated, as Kathleen 'loves research, being at the bench, learning new things and putting the pieces of the jigsaw together'. However, the possibility of working for the Society (of which she had been a member since returning to New Zealand), in a permanent position that enabled contact with, and promotion of, science, was a very attractive option. She now sees a new career path for herself, with the wherewithal to remain closely involved with science and people within the research community.

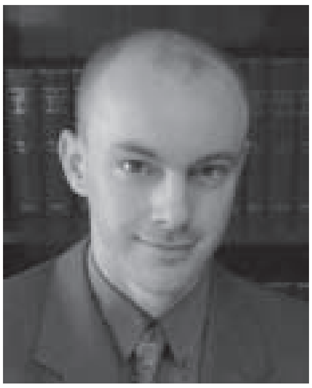
Similarly, Dr Weston left materials science for computer programming and received greatly improved terms and conditions. As a programmer he had a wide choice of employment opportunities in Wellington. However, he is fundamentally a scientist and would like to work as one. Hence, he moved into science policy, with the intention of improving the research system to the point where returning to the science profession would seem once again an attractive option. The instability of research careers these days is something of which Kathleen and Jez have personal experience, and they both appreciate the importance of improving career structures so that capable people will be attracted to the profession.

The CEO of the Royal Society, Dr Steve Thompson, was keen to employ policy analysts with direct experience of the research system here (and overseas), and was not unduly worried by their lack of direct policy experience. It is of vital importance that research, science and technology policy be developed by those with relevant experience, rather than solely by economists and professional managers. Drs Logan and Weston are already developing links with other policy groups around Wellington, and with the other purchase agents (HRC and FRST).

Responsibilities of the Unit

The membership of the RSNZ has expressed its wish that the Society become more involved in analysing the state of science in New Zealand, and influencing policy by encouraging evidence-based policy (http://www.rsnz.org/members/memsurvey2003.pdf). As it is a non-government organisation, incorporated by an Act of Parliament (to promote science and technology), the RSNZ is well positioned to act as a conduit for the expertise among its membership to inform public policy in New Zealand.

In the past, committees of the Council of the RSNZ were convened in order to deal with specific science-related issues, thus providing an important route for the incorporation of new knowledge into government policy. These issues have included climate change, codes of practice and ethics, and research capacity. Generally, these committees deal with long-standing issues that are very complex and that need a mix of expertise for the development of solutions. These volunteer committees continue to provide an important service, through analyses of key issues and their implications for researchers in New Zealand.



Jez Weston obtained his BEng in Materials Science and Engineering from Bath University, UK. For his PhD research he studied laser welding of aluminium at Department of Materials Science and Metallurgy, University of Cambridge. As an STA Fellow, he then worked on cracking in rocket nozzles at the National Institute of Materials in Tsukuba Science City, Japan. After a period as a software programmer, in October 2004 he took up a position at the Royal Society of New Zealand as a Policy Analyst. Dr Weston may be contacted at jez.weston@rsnz.org.nz

Dr Kathleen Logan was, until recently, a reproductive physiologist working for AgResearch. She has a BSc majoring in zoology (University of Canterbury, NZ) and a PhD in human reproductive physiology (University of Newcastle upon Tyne, UK). She has 11 years' laboratory research experience, including: studies at University of Cambridge investigating genomic imprinting and neuroscience; as well as in New Zealand studying embryology, transgenics; and five years' post-doctoral study of ovarian physiology, genomics and bioinformatics. Now Kathleen is at the Royal Society of New Zealand in her new role as a policy analyst. Dr Logan may be contacted at kathleen.logan@rsnz.org.nz

However, from time to time, issues arise that must be dealt with in a quicker, more reactive way, and the Policy Unit will serve in this niche. Dr Thompson, who up to now has performed this latter function, has assigned watching briefs to Drs Weston and Logan, according to their interests and strengths. Table 1 summarises their respective responsibilities

The Society intends to strengthen the work of its committees by putting in place an additional infrastructure that enables the creation of diverse committees and review panels for short-term projects. These committees will be convened and supported by the Policy Unit. The new infrastructure will formalise the way the RSNZ provides peer-reviewed, expert advice for issues important to government departments, industry and academia.

The Human Resources Project

The Human Resources Project is assigned to Dr Logan under the leadership of the Human Resources Committee, convened by Professor Ian Pool (FRSNZ) of the University of Waikato. Professor Pool was recently appointed to an Expert Panel for the International Council for Science on 'Capacity Building in Science'.

Government seeks to maintain and increase scientific and technological research capabilities in New Zealand, and to promote a more innovative culture. Of course, such capabilities depend on people, but little is known about the human face of research, science and technology, particularly its demographics. MoRST has agreed to part-fund this project from Vote RS&T in order to ensure that the information gap is filled.

This project will develop an evidence base in New Zealand to inform debates that currently spring largely from anecdotal evidence: Is there a brain drain or a brain exchange, or is the exchange equal? What are the demographics of scientists and technologists in New Zealand? In which fields of study are we short of experts? Are the investments we make in our scientific training paying off? Will retirements clean out a particular field, creating a shortage of expertise to train new talent? Are we training too many young scientists in areas of limited demand, thereby consigning them to emigration? The database will provide information that describes researchers by discipline, training, qualifications and demographics, and will ultimately inform on supply, demand, and international flows of human resources in public research in New Zealand. Initially, the database will be limited to researchers in technology and science, including social science.

Several agencies gather information annually on human resources for funding evaluation, such as Marsden, HRC, FRST, and now the PBRF. However, there is no agreed manner in which this information is to be collated and analysed. The Human Resources Project is a long-term programme that involves agreement on a mechanism for the collation of data currently residing in diverse information bases around New Zealand, and a system for continually updating the database. The RSNZ will then analyse the data in order to provide the evidence required for informed debate on research, science and technology capability issues in New Zealand. The Society believes that those who devote their careers to research will be encouraged if policies regarding human resources are based on sound evidence.

The Biotechnology Science Scan

The Biotechnology Science Scan (also overseen by Kathleen Logan) is an element of a larger MoRST study to produce a biotechnology 'futurewatch' document. This initiative is part of implementing the recommendations of the Royal Commission on Genetic Modification, and the subsequent 'Biotechnology Strategy' (http://www.morst.govt.nz). While the RSNZ is funded by MoRST to perform the 'science scan', other organisations are providing information on other aspects of biotechnology, such as spiritual and ethical (Bioethics Council) or industrial (New Zealand Trade and Enterprise).

The Science Scan is designed to look for new methods or discoveries that are currently being developed in the lab and that may impact on society or science in 10 to 20 years from now. Early notice of new scientific or technological discoveries may inform policy decisions and better enable New Zealand to capture benefits, develop communication strategies, militate against hazards and dangers, and develop appropriate regulatory systems.

The Society has gathered a select team of experts from diverse areas of biotechnology in order to take part in the scan.

Table 1. Outline of responsibilities within the Royal Society of New Zealand Policy Unit.

	Kathleen Logan	Jez Weston
Specific projects assigned	Human Resources project http://www.rsnz.org/advisory/hr/ Biotechnology Science Scan	'Setting Directions' Workshop http://www.rsnz.org/news/policy/srdf/ Science-Industry interface http://www.rsnz.org/other/job/
Kathleen and Jez work together on…	Annual Performance and Achievements Report to Government	Strategic Plan Sustainable Development
Watching brief (policy implications in these areas)	Antarctic Sciences ANZCCART Biodiversity Education Genetic Modification Human Resources in RS&T Maori in RS&T Performance Based Research Fund Primary Resources Social Sciences	Climate Change Ethics Workshops FEAST – Forum for European and Australasian Science and Technology International Geosphere–Biosphere Programme Math & Information Sciences Physical Sciences & Technology Publications Open Access proposal

The project is already under way, and the RSNZ is very excited that its members, and the wider scientific and technological community, are contributing in this way to MoRST's biotechnology futurewatch.

The Setting Research Directions Forum

The forum on Setting Research Directions has been assigned to Dr Weston under the guidance of Professor Jacqueline Rowarth and Paul White, Royal Society Council members.

Following presentations from a range of international speakers this year, the RSNZ Council decided that it was time to hold a forum to review and learn from the recent changes in the way that New Zealand goes about setting research priorities. The forum will therefore consider New Zealand's priority-setting system in the light of international experience.

At present, Government hands down high-level goals and objectives to the research, science and technology administration. The forum will discuss the systems used to translate these goals into priorities for government investment in research. A range of systems are used overseas, with varying degrees of centralisation, prescription and complexity. The forum will investigate the strengths and weaknesses of these systems and report on international trends in priority-setting to find out what these trends can tell RSNZ about the New Zealand system, its advantages and disadvantages, and identify options for improvement.

The forum will be held on 10 June 2004, at Science House in Wellington. Speakers will come from both international and New Zealand research, science and technology administration, from industry and research. The Society hopes that many working researchers will attend and engage in dialogue with policy-makers.

Prior to the forum, an evidence base will be made available in order to inform the discussion. The RSNZ will provide summaries of existing relevant literature and links to existing studies.

The science–industry Interface

Traditionally, the Royal Society has focused on the 'education' and 'awareness' end of the innovation spectrum. However, the Council sees a growing role at the other end of the spectrum, where science and industry connect.

There are many players in this area already, including MoRST, FRST, the Ministry of Economic Development, NZ Trade and Enterprise, regional development corporations, and business development units within universities and CRIs. However, there are many tasks to be accomplished.

The Society hopes to begin by building up a clear picture of how the science-industry interface functions. RSNZ wants to research the operation, scale and effectiveness of the science-industry interface, and study how business sets its own priorities and how national systems can interact with business. The Society wishes to promote private research investment and promote incentives for effective investment. RSNZ has just completed an international study into tax incentives for research and development, and will disseminate the findings of that study. The growing evidence base will help to target the Society's actions.

The Society will also be learning by doing. It is beginning with three pilot schemes, Face to Face, Place to Place, and the Fusion jobs interchange website.

Face to Face will build on the success of the RSNZ Science Communicators workshop. This workshop has given working scientists an opportunity to improve their skills and their ability to communicate with general audiences. The Society now has 120 speakers in our Science Communicators' Programme. RSNZ wants scientists to develop similar skills for engaging industry and so it is setting up a similar, but more specific, course. This course is aimed at promoting mutual awareness and understanding, helping scientists and businesspeople to talk the same language, and developing scientists' understanding of how business makes and owns decisions.

Place to Place will be a fellowship aimed at promoting mutual collaboration between business, and scientists and technologists. FRST manages other fellowships in this area, but these are project-based. Place to Place will be people-based, and aimed at giving businesspeople the opportunity to spend time with scientific organisations, and vice versa.

To help develop interchange opportunities between business and science, RSNZ sees a need to act as a 'dating agency', providing ways to bring together these disparate partners. Hence, it is setting up Fusion, a jobs interchange website, as a way to assist people and companies in arranging temporary placements. This initiative focuses on assisting science and technology specialists to find work in industry, and on assisting managers and specialists to move across to work in research agencies. These are all flexible, simple schemes, in which the RSNZ will enable people to meet and learn from each other.

Finale

The activities of the Royal Society of New Zealand are more diverse than many realise. In addition to its work in administering several Government funds, including the Marsden Fund, ISAT Linkages Fund, and the James Cook Research Fellowships, RSNZ is involved in science and technology promotion. The Society runs programmes in education and communication. It promotes science-related events, publishes journals for New Zealand, and presents medals for excellence in science and technology. An in-house policy capability is a natural extension of the work provided by members and others who serve on the RSNZ committees. RSNZ aims to provide an efficient conduit to allow the expertise of its membership to inform policy in New Zealand.

Sociobiology

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Introduction

'Sociobiology' is the study of the social organisation of biological entities, and was the subject of an influential book by Wilson (1980).

The 'Father of Sociobiology' (as pointed out by Dennett 1995) is Thomas Hobbes, who, in his *Leviathan* (Hobbes 1651), drew an analogy between the social organisation of the human body, and that of human society. The frontispiece to his book illustrates this point vividly (Figure 1). The following is a quotation from the book:

> *For by Art is created that great LEVIATHAN called a COMMONWEALTH OF STATE which is but an Artificial Man; though of greater stature and strength than the Natural; for whose protection and defence it was intended; and in which the Sovereignty is an Artificial Soul, as giving life and motion to the whole body.*

Social organisation takes different forms and operates at several levels. The human body is a society of specialised cells, all originating from one embryo. Such a form of social organisation, identified by a surrounding membrane called an 'epithelium', or skin, is described as an organism, classified by taxonomists according to the familiar biological hierarchy.

Darwin was himself a pioneer in sociobiology, particularly in his work on the expression of emotions in man and animals (Darwin 1872), and on his study of sexual selection, which forms the major part of his *Descent of Man* (Darwin 1874). In his major work (Darwin 1859) he treats species as much as a social group as an individual. He also emphasises its arbitrary character as a mere element of classification.

Multi-level evolution

Evolution operates by selecting those parts of each generation which have been most successful in surviving. It takes place not just at the individual level, but at every level. It selects the fittest genes, cells, organisms, groups, societies, and nations, all simultaneously. Reproduction mechanisms are often different for each group. 'Democracy' is adopted by others if it is

Figure 1. Picture of Leviathan, reproduced from the frontispiece of the book, Leviathan, by Hobbes (1651).

successful in survival and prosperity, but it is not a 'reproductor' in Dawkins' terms. All the same, the evolutionary success of

Vincent Gray has a PhD in Chemistry from Cambridge University and has enjoyed a long career in scientific research in UK, Canada, France, China and New Zealand, with well over 100 scientific publications in petroleum, coal, timber, building, paint, and forensic science.

He has recently specialised in environmental matters, particularly climate science, and theoretical biology.

democracy will assist the reproductive success of individuals in democratic societies. Similarly, the failure of a dictatorship reduces propagation of the individuals within it. Social evolution goes beyond the 'memes' and 'extended phenotype' of Dawkins (1983) and his followers, and even extends to the whole earth, as with Lovelock's Gaia (Lovelock 1989). Each level of social organisation evolves in much the same way as an individual organism.

Individual ants and bees are surrounded by a skin, and therefore each is an organism. Each individual originates from a restricted reproductive system and is controlled by chemical signals in a similar way to the individual cells in an isolated organism, so that the whole society behaves in a similar way to a single organism. Associated organisms such as the Portuguese man o'war or the lichen are difficult to classify by the conventional system because apparently different organisms form a very intimate social group.

Evolution takes place by selection of the fittest individual, organism, social grouping, nation, or global population – all simultaneously. With nations it takes the form of a 'clash of civilisations' (Huntington 1996). Human survival and prosperity is important at the level of the gene and the local society, but it is ultimately dependent on the result of these larger clashes. Since these larger clashes are capable of very great destruction, our future may depend crucially on our ability to develop local and international procedures for resolving conflicts without violence and destruction. It is at this level where 'altruism' really needs to be promoted.

Eugenics

Those who emphasise the importance of individual genetic fitness often forget that the survival and prosperity of the society as a whole are as important as the fitness of an individual. Eugenics, invented by Francis Galton in 1883, seeks to speed up evolution by selection of favourable human characteristics for breeding. Many desirable human characteristics, such as intelligence, genius, or athletic skill, cannot exist without social input, so an exclusive emphasis on individual heredity is often unsuccessful.

Genetic fitness obviously plays an important part in the fitness of society, and those individuals possessing identified genetic defects, at least, should be discouraged from producing offspring. Non-reproducing groups ('freeloaders') are not necessarily a burden on society or incapable of participating in evolution, as they may make important contributions to the fitness and survivability of the society itself.

'Social Darwinism' suffered a severe blow from the policies of Nazi Germany, which sought to improve genetic fitness by designating one 'race' as superior and encouraging breeding of 'Nordics' while exterminating 'inferior' races and the handicapped. These policies did more damage to the general fitness of the society, by their condoning of murder, whatever they did for the genetic fitness of individuals.

In 1986, Singapore became the first democratic country to adopt an openly eugenic policy by guaranteeing pay increases to female university graduates when they gave birth to a child, while offering grants towards house purchases for non-graduate married women on condition that they were sterilised after the first or second child.

Steven Pinker in *The Blank Slate* (Pinker 2003) tells the story of a US Nobel Prize-winner, George Wald, who was contacted by a high-profile sperm bank which wanted him to supply his sperm. He told them that his sons were both guitar players, and the man they really wanted was his father, who was a poor Polish immigrant tailor. The point is that effectiveness of an individual in society, and effectiveness of the society as a whole, are not determined exclusively by the genetic properties of individuals but by a complex system which certainly includes individual genetics, but also the effectiveness of the entire social system.

The origin of life

Social organisation evolved from an assumed primordial life form. There are two extreme possibilities. One is that there was only one such form. There are some chemical reactions which are common to the whole of life on earth, and there is no evidence that our special form, or any other, has succeeded in coming into existence since the original event.

The other extreme view argues that life will come into existence as soon as circumstances favour it. This view is popular with those who seek life elsewhere in the universe, but there is no evidence that it is true.

The closest we are today to the original life form is the prokaryote cell, a cell without a nucleus, thought to have evolved as long ago as 3½ billion years ago. It is present today in many of the less complex organisms. This kind of cell is thus the earliest living ancestor of every creature, alive or dead. Viruses and prions (responsible for mad cow disease) are thought to be more recent parasites.

Most of the more complex organisms are based on eukaryote cells which evolved from prokarytote cells some 1½ billion years ago. They possess a nucleus and other important features. This kind of cell represents the direct ancestor of a large majority of the more complex living organisms, including humans.

A crucial early evolutionary development was the ability to exchange nucleic acid genetic material as part of the reproductive process, an ability which greatly increased the variability of offspring, and thus survival in response to change. This process became differentiated into the two sex partners. The biological literature is full of articles trying to explain the burden to the organism of the existence of sex, but it is surely justified by its importance for survivability. There are still many organisms that reproduce without sex, but their limitations in genetic variability are always a threat to their survival by comparison with those which practise sex.

Kin selection and altruism

In a recent copy of *New Zealand Science Review,* it was claimed (Segerstrale 2003) that the 'father of sociobiology' was Bill Hamilton, on the strength of his 1964 theory of 'kin selection' (Hamilton 1963), a theory endorsed by Wilson (1980) in his *Sociobiology*.

Hamilton and his followers tend to ignore social evolution and assume that the only goal of evolution for an organism is survival of their own genes, as suggested by Dawkins (1976) in his *The Selfish Gene*. For them, the existence of social organisation at all is a puzzle, as helping others conflicts with the selfishness of the gene. Social co-operation, described as 'altruism', implies that a biological entity has a free choice of whether to co-operate or not.

For example, it is surmised that the reason why worker ants should choose to remain in their miserable sterile caste is that they are assisting in the reproduction of genetically similar individuals to themselves, so satisfying the craving of their own, otherwise frustrated, genes. This theory tends to ignore the greater or lesser measures of compulsion that are present in all social groups, designed to ensure that social structure is preserved. There is only a limited choice, and often very little altruism at the level of the individual.

Take, for example, the human body, which consists of a very large number of specialised cells, all emanating from a single act of reproduction, organised into a society by a rigid system of genetic determinism backed up by complex chemical controls. Only one kind of cell is involved in reproduction. The rest simply have to co-operate. There is no choice. If, as occasionally happens, any one of them escapes their biological straitjacket, the resultant uncontrolled growth is a cancer, threatening the potential death of the whole organism.

The ants and the bees are similarly organised by genetics and chemistry, both as individual assemblies of cells surrounded by an epithelium, and as a society without one. There is only one, or a few, reproductive units, so the other castes have a similar pre-ordained fate to the cells in each ant body. Only the specialist reproductive cells in the queen are involved in evolution. Each caste is forced into its individual role. The free choices take place at a higher level, in such matters as how many of the two castes should be reared, or when a new colony should be formed.

Instincts

Animal societies also employ genetics and chemistry to control social structure. Instincts are behaviour patterns more or less determined by genes (and previous evolution). Reproductive behaviour is very largely controlled by genetics. Most social creatures have a rigid dictatorial hierarchical structure, honed by the pressures of survival. Those who 'choose' not to conform are likely to be killed.

Many aspects of human society are controlled by inherited instincts. A recent BBC programme by (Lord) Bob Winston elaborated on the many human instincts, many of which involve chemical controls called hormones.

Instincts that may have evolved, as necessities, in earlier periods of development may not always be so valuable at a later stage. In a BBC series, *Genetics*, David Suzuki visited a sheepdog trainer and asked him how he chose his dogs. The trainer pointed out that dogs are wolves. They have an inherited instinct to kill sheep, in packs. His job was to select, from the variability always available, those dogs whose killer instinct was relatively weak, and whose capacity to learn was comparatively strong, and use these for training. Those dogs less capable of training were rejected. Human training is not very different from this.

Skill and enjoyment in killing would have been a useful, and eventually inherited, trait in early human society. It is still encouraged in war and in sublimated blood sports. While generally controlled by laws and education, there are some who can still evade the controls, and help provide the crime statistics. The idea that freedom from government would lead to an ideal society is the basis of the doctrine of anarchism, which played a part in the Russian revolution and the Spanish Civil war. It is recently advocated by Ridley (1996) in his *The Origins of Virtue*. Unfortunately, as expounded in *The Lord of the Flies* (Golding 1954), and at a more practical level amongst the mutineers on Pitcairn Island and the kibbutzes of Israel, as well as in the genocides of Rwanda and Bosnia as soon as the government permits, it does not seem to work. Human societies really do need controls on their more unsociable instincts.

The most basic instinct of all is selfishness, from the selfish gene upwards. If it were the overriding instinct, there would be no social organisation at all, not even as in multicellular organisms. If kin selection is adopted as the major feature of sociobiology, as is done by Hamilton and Wilson, it could justify Nazism, racism, euthanasia and 'Social Darwinism'.

Instincts almost always require a social situation for their expression, a fusing of 'nature' and 'nurture', which is the subject of a recent book by Ridley (2003). The concept of 'nurture' tends to be treated too narrowly, applying mainly to family life, without paying attention to important influences from outer layers of society, such as poverty, unemployment, war, and political, racial, religious and gender repression.

One of the best examples of the interaction between genetic and social influences is the language instinct, discussed by Chomsky (1975) and made more popular by Pinker (1994). The basic structure of all languages is present in human genes and is inherited by all our children. The ability is enhanced by special expansion of part of the brain below the age of about twelve years. In a famous experiment, a collection of deaf-mute children was raised together, and it was found that they invented their own, original, sophisticated sign language without outside help. However, children deprived of society from birth never learn to speak.

Another important instinct, so necessary for hunter–gatherers, is the worship of authority, both of people and of doctrine. This may be a severe handicap for a modern human society whose survival is increasingly dependent on more widespread exercise of public participation, the encouragement of innovation, and the ability to make use of the talents of the whole society.

Religion is one means of enforcing obedience to authority as well as supplying a basic moral code. In providing support for authority it discourages political change and provides a fossilised moral code, based on out-of-date writings and obsolete ideas. It imposes absurd rituals. For example, the ban on eating pork by Muslim, Jewish and Hindu religions goes back to an ancient conflict between hunter-gatherers and pastoralists. A more recent excuse, that pigs are unclean, is equally spurious. Religions may also perpetuate discrimination against women, minorities, and non-believers and have often been an important contributor to violence and war.

The uniqueness of humans

Humans cannot be excluded from evolution, but the idea that humans are unique, different, and better than the others has a very ancient origin. Few people, even biologists, are prepared even now to abandon it. Julian Huxley put it this way (Huxley 1942):

> *The last step taken in evolutionary progress, and the only one to hold out the promise of unlimited (or indeed any further) progress in the evolutionary future, is the degree of intelligence which involves true speech and conceptual thought and is found exclusively in man.*

It is true that humans have secured advantages in their struggle to survive and progress by their development of advanced conceptual ability and the use of technology. But this does not guarantee evolutionary progress, whatever that may mean. There are many organisms which progress from an evolutionary point of view without the advantages of humans but possessing others, such as small size, rapidity of reproduction or mutation, or capacity for parasitism which could lead them to replace humans. We have to be aware of the challenges of evolution and avoid arrogance and complacency in facing them. It is only recently that the main nations of the earth threatened to exterminate all of us with nuclear weapons, and this threat has by no means disappeared.

Huxley places great weight on our intelligence, but do we make use of it? In the USA, 25% of the population believe in witches, 41% in possession by the devil, and 45% believe that aliens are stalking the earth. Large numbers believe that there are superior beings controlling human destiny, and the current environmental religion believes that we are responsible for all living organisms, that evolution is caused exclusively by humans, and must or can be stopped because it is always bad. It is time that we showed less concern for threatened species and more concern for recently evolved organisms, such as AIDS, SARS, influenza and others, which actually threaten humans.

The Romantic Movement

The Romantic Movement which spread in the early 19th century has helped us to develop our individual personalities, but it is in many respects anti-human, as it places more importance on feelings and aesthetics than on facts and evidence. It has been partly responsible for the horrors of Nazi Germany and Soviet Russia. It tends to promote ideas of racial superiority and euthanasia.

The Romantics have persuaded many of us to prefer 'nature', a world without humans, to our own lives and actions. It is the basis for our current artificial distinction between the activities of human society and the rather static behaviour of the 'environment'.

A persistent Romantic fallacy is that of the Noble Savage: the idea that primitive peoples are somehow free from the stresses and problems of civilised society, and that we can solve our problems by going 'back to nature', and embracing a primitive lifestyle. This myth is so strong that it has engulfed the supposedly scientific discipline of anthropology, so that famous anthropologists like Margaret Mead could be hoaxed by mischievous Samoans (Francis 1996), and where the honest investigations of Napoleon Chagnon (1983) can be attacked. Chagnon actually finds that primitive people behave in very similar ways to modern humans. They fight clan wars, mainly over women, they beat their wives, are addicted to tobacco, and they believe in witch doctors and primitive gods.

The arrogant fantasy that humans are the highest form of evolution and must organise the whole earth to suit themselves can be contrasted with the parallel arrogant fantasy that humans inevitably destroy their environment and are doomed to extinction.

A balanced view

A balanced view can be found from the theory of evolution. The continued survival of the human race is by no means certain, but neither is its doom inevitable. Humans have advantages for survival, but they are not necessarily guarantees of survival. We have a tendency to recognise only creatures of our own size and ignore the many advantages of being smaller. Many times in the earth's history there has been a tendency for competing creatures to grow larger, for protection, but the disadvantages in lack of flexibility, and an increasing demand for territory and food, tend to their eventual extinction and replacement by smaller creatures. The dinosaurs were successful for 140 million years, but extinction was eventually inevitable. Large animals in our world were in decline before the emergence of humans. Elephants and blue whales are extremely vulnerable to slight changes in climate and food supply. Humans are, perhaps, more resilient, but they have to be aware of the definite advantages of being an insect or a virus.

Humans must develop controls, and eventually instincts, which promote co-operation on an international scale, instead of just the tribal and national scale. This is where 'altruism' comes into its own. The slaughter and damage of the two World Wars was eventually repaired, but a nuclear war might not be so easy to repair. International peace organisations have not proved very effective. The League of Nations, set up after World War I, collapsed because nations would not support it, and the United Nations, set up after World War II, is today under threat from those nations which insist on waging war without its sanction. It is vital for the survival of the human race that effective international control of war and violence is pursued with vigour. The replacement of war with peace, and an effective mechanism for its continuance, are essential for our survival, and we must avoid being distracted from this goal by arrogance or pessimism. 'Democracy' and 'Freedom' are highly desirable objectives, but they should be promoted within all nations as well as internationally.

Conclusions

Evolution takes place at many levels: DNA itself, the cell, the organism, the social unit, the society, the nation, the international community, the entire world, and all of these different levels ultimately influence reproduction by favouring individual genes against others. The concept of altruism is often out of place in the earlier levels, where techniques of compulsion prevail, but it becomes more necessary at the upper levels. Social influences on evolution go far beyond the 'nurture' supplied by a family or small social unit. Human evolution and survival are not guaranteed unless we promote altruism amongst humans at every level, particularly on the local and the international scales.

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New Zealand and Bellingshausen*

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Russian Antarctic Expedition 1819–1821

The Russian Antarctic expedition (1819–1821) was designed to go south of the Antarctic Circle, outside the three regions where Captain Cook had gone in 1774. The expedition discovered the first land within the Antarctic Circle ever to be seen by humans.

Captain Fabian Gottlieb von Bellingshausen (1778–1852) led the expedition on the sloop *Vostok*, with Mikhail Patrovich Lazarev (1788–1851) as commander of the transport *Mirnyy*. The astronomer for the expedition was Ivan Mikhailovich Simonov (1794–1855), Professor of Astronomy at Kazan University and the closest friend of the great mathematician Nikolai Ivanovich Lobachevsky. In addition to geographical discovery, ethnographic data about people in the Pacific Ocean was a major objective of the expedition.

The expedition sailed from Kronstadt on 1819 July 4 of the Julian calendar (which was then 12 days behind the Gregorian calendar). Accurate charts were made of South Georgia and the South Sandwich Islands; and on 1820 February 18 the explorers viewed an immense ice-cap to the south, rising up to mountainous heights. That was actually the earliest known sighting of the Antarctic continent; but Bellingshausen cautiously did not commit himself to declaring that ice to be supported on land rather than floating in the ocean as a vast iceberg. The ships arrived at Port Jackson on 1820 March 30 and April 3, and they sailed on May 8 to explore the Tuamotu Archipelago during the southern winter. The ships could not get past North Cape, and so Bellingshausen headed for Queen Charlotte Sound, where they stayed from May 28 to June 3 (Julian calendar). The journals of Bellingshausen and several other members of the expedition describe their very friendly encounters with the Māori people throughout their stay, with brisk well-regulated trading. In particular, Simonov acquired many artefacts, including some fine cloaks and some incomplete specimens of woven flax, which reveal the method of manufacture [Glynn Barratt, *Bellingshausen, a visit to New Zealand: 1820.* Dunmore Press, Palmerston North, 1979, pages 111–113 & 118–119].

In the eastern Pacific the expedition produced accurate charts of many islands, and detailed accounts of encounters with the Polynesians. The ships returned to Port Jackson on 1820 September 9 and 10, and departed on 1820 October 31 for their second Antarctic voyage. They arrived at Macquarie Island on November 17 and departed on November 18 (Julian calendar). Sailing to the east of Captain Cook's southernmost voyage, the expedition discovered the first land ever seen by humans south of the Antarctic Circle – the small island named after Peter the 1st and the much larger land named after Alexander the 1st. The expedition returned triumphantly to St Petersburg in August 1821.

Published accounts

Bellingshausen's journal was published in 2 volumes in 1831, as *Dvukratnye izyskaniya v Yuzhnom Ledovitom okeane i plavanie vokrug sveta, v prodolzhenie 1819, 1820 i 1821 godov, svershennye na shlyupakh "Vostok" i "Mirnom"*, SPb, 1831 (*Repeated Explorations in the Southern Icy Ocean and a Voyage Round the World in 1819, 1820, 1821, performed on the sloops "Mirnyy" and "Vostok"*, St Petersburg, 1831), with an *Atlas* of lithographic illustrations published separately.

On that expedition, the artist Pavel N. Mikhailov was the first professional artist in New Zealand since Cook's Third Expedition. The lithographs in that *Atlas* include a view of the Māoris entertaining their Russian visitors with a haka, and portraits of a Māori chief and his wife at Little Waikawa Bay. However, in the 18th and 19th centuries, when explorers brought to Europe portraits of non-European people, those portraits were usually 'corrected' by European publishers, so that the published portraits were in accord with European expectations. In particular, that *Atlas* (1831) portrays Māoris and other Polynesians, Australian Aborigines and Fijians, all with bland round faces and somewhat Slavonic features. But Mikhailov's original drawings of that Māori chief and his wife are much more realistic than the published lithographs [Glynn Barratt, *Russia in Pacific Waters, 1715–1825: a survey of the origins of Russia's naval presence in the north and south Pacific*. University of British Columbia Press, Vancouver & London, 1981, Plates 18 & 19].

War Dances of New Zealand South, in Queen Charlotte Sound, by P.N. Mikhaylov; lithographed by I.P. Fridrits (1823–24). [From Barratt 1979, pl. xxxv.]

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During the 19th century, Bellingshausen's expedition remained almost unknown outside Russia. In 1902 an abridged German translation of Bellinghausen's journal (without maps!) was published: *Forshungsfahrten im Südlichen Eismeer, 1819-1821: Auf Grund des russischen Original-werks*, S. Hirsel, Leipzig, 1902.

In the early 20th century the politician Robert McNab began his remarkable researches into the early history of southern New Zealand. "Nothing has surprised the author more, during his long search, than the great mass of discovery work found placed upon record in books but never translated into our language and the number of great explorers, scarcely known to our writers, even by name. With two of these we are brought into contact in the present work; the great Spaniard Malaspina, and the equally great Russian Antarctic explorer, Bellingshausen. The former visited Doubtful Sound in 1793, the latter, Macquarie Island in 1820. The British Museum knows of no English translation of the work of either, although an abridged German translation is to be found of the latter. Yet with the exception of Cook, we have produced no navigator greater than either of them... Bellingshausen's visit was discovered through mention being made by the captain of a sealing vessel called the *Regalia*, when she arrived at Hobart Town from Macquarie Island in March 1821, that two Russian vessels had called there for wood and water. Search in the Sydney files of that date revealed the name of the commander and the nature of the expedition, and the catalogue of the British Museum showed where there was to be found a published narrative of the voyage. The translation makes Chapter XVII and throws more light upon the methods and daily life of the early sea-elephant hunters of the southern sea, than anything written in our language. It should be mentioned that Bellingshausen visited the mainland of New Zealand and spent some time in Queen Charlotte Sound." [Robert McNab, *Murihiku and the Southern Islands*. William Smith, Invercargill, 1907, Preface, p.ix].

In Chapter XVII, '*Russians at Macquarie Island, 1820*', McNab explained that "The visit of the expedition is told in the leader's own words in the narrative following and attention is called to it, first as a translation from an exceedingly rare Russian work and secondly as the best word picture of the life of the Macquarie sea-elephant hunter ever penned. When we recollect that our nation supplied, almost without exception, the skin and oil hunters of the far south during those early days, it seems marvellous that we should have to go to a Russian source to learn how they did their work." Bellingshausen's account of the visit to Macquarie Island, on 1820 November 17–18, is translated on pages 190–198. McNab did not include Bellingshausen's account of Queen Charlotte Sound, since that was outside the southern regions of New Zealand. But in 1909 McNab published a new edition of *Murihiku* (Whitcombe & Tombs, Wellington & Christchurch, 1909), expanded from 377 pages to 499 pages, with its scope enlarged to cover the entire South Island and the southern North Island, up to 1830. That 1909 edition includes a chapter with a translation of Bellingshausen's account of the visit to Queen Charlotte Sound in May 1820.

The 1907 edition of *Murihiku*, with Bellingshausen's account of Macquarie Island, has twice been reprinted in facsimile editions [Wilson & Horton, Auckland, 1970; and Kiwi Publishers, Christchurch, 1996]. But the enlarged edition of 1909, with Bellingshausen's accounts of Queen Charlotte Sound and of Macquarie Island, has never been reprinted.

A complete English translation of Bellingshausen's narrative was worked on by several people over many years, before it was published by the Hakluyt Society in 1945 [*The Voyage of Captain Bellingshausen to the Antarctic Seas, 1819–1821* (2 volumes), edited by Frank Debenham, Hakluyt Society, 2nd series, No. 91, London, 1945].

Glynn Barratt gives translations of the accounts of Queen Charlotte Sound by Captain Bellingshausen, the astronomer Simonov, the midshipman Pavel Nikol'sky, the surgeon Nikolay Aleksandrovich Galkin and the leading seaman Yegor Kiselyov [Glynn Barratt, *Bellingshausen, a visit to New Zealand: 1820*. Dunmore Press, Palmerston North, 1979].

Māori collections in St Petersburg, and in Kazan

Bellingshausen had been instructed by the Naval Minister that all objects collected on the expedition were to be presented through him to the Tsar. Consequently, the Miklukho-Maklay Institute in St Petersburg has a rich collection of early Māori artefacts, from Queen Charlotte Sound [*Bellingshausen, a visit to New Zealand: 1820*, Plates 1–34, pages 107–111 & 115–118]. Simonov presented 37 ethnographic items, including 11 Māori items, to Kazan University [*Bellingshausen, a visit to New Zealand: 1820*, pages 111–113, 118–119 & 130]. The I.M. Simonov Collection of Oceana, in the Museum at Kazan University, has grown to a major ethnographic collection of several thousand items. Both collections of Māori material from the Antarctic Expedition, in the Miklukho-Maklay Institute and in Kazan University, are very important early collections of artefacts made by Māoris who had been very little influenced by Europeans.

Barratt explains (p.130) that "Most of the artefacts concerned, however, were by 1822 in the keeping of the Ministry. Some – mostly duplicates of specimens held in the capital – were quickly handed back to Simonov (if in fact they were ever separated from him)."

When the expedition returned triumphantly to St Petersburg in August 1821, Simonov was delighted to find that his best friend Lobachevsky was there. He had arrived on July 25, on half-year leave from Kazan University, and he was buying mathematical books and scientific instruments for Kazan University. Simonov and Lobachevsky returned together to Kazan, on 1822 February 21. On 1822 May 4, Lobachevsky reported to the university Council on his leave in St Petersburg. He told that he had arranged for the books and instruments to be transported to Kazan, together with those things recently presented to the Council, which had been collected by Professor Simonov on his travels.[Abrar Gibatullovich Karimullin i Boris Lukich Laptev, *Chto Chital N.I. Lobachevski, Zapisi Knigi i Zhurnalov, vydannye N.I. Lobachevskomu iz Biblioteki Kazanskogo Universiteta*, Izdatelstvo Kazankogo Universiteta, Kazan, 1979. (Abrar Gibatullovich Karimullin & Boris Lukich Laptev, *What N.I. Lobachevsky Read, a List of the Books and Journals borrowed by N.I. Lobachevsky from the Library of Kazan University*, Kazan University Press, Kazan, 1979. *Appendix 1, List of Books on the Physico-Mathematical Sciences, obtained at the choice of N.I. Lobachevsky in 1821 in Petersburg*, pp. 111–112.]

Thus, Simonov's important collection of early Māori material is now in the Museum of Kazan University, thanks to the great mathematician Nikolay Ivanovich Lobachevsky.

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