

# **Evaluation of BBSRC Plant and Microbial Sciences Committee Responsive Mode Portfolio**

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This document represents the views and conclusions of a Review Panel of experts in plant and microbial sciences.

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## ABBREVIATIONS

AF:	Agri-Food Committee
BBSRC:	Biotechnology and Biological Sciences Research Council
BIS:	Department for Business, Innovation and Skills
BMS:	Biomolecular Sciences Committee
CASE:	Collaborative Awards in Science and Engineering
Defra:	Department for Environment, Food and Rural Affairs
DfID:	Department for International Development
EBS:	Engineering and Biological Systems Committee
EU:	European Union
FoF:	Follow-on Fund
GARNet:	Genomic Arabidopsis Resource Network
HEFCE:	Higher Education Funding Council for England
IGER:	Institute of Grassland and Environmental Research
IPA:	Industrial Partnership Award
MRC:	Medical Research Council
MRSA:	Methicillin-resistant <i>Staphylococcus aureus</i>
NERC:	Natural Environment Research Council
NI:	New Investigator
PI:	Principal Investigator
PMS:	Plant and Microbial Sciences Committee
RA:	Research Assistant
RCUK:	Research Councils UK
RAE:	Research Assessment Exercise
REF:	Research Excellence Framework
TB:	Tuberculosis

## EXECUTIVE SUMMARY AND KEY CONCLUSIONS

This document sets out the views of a specialist Review Panel convened to provide an independent evaluation of the research supported in responsive mode through the BBSRC Plant and Microbial Sciences Committee (PMS) since 1996. The objectives of the evaluation were to assess the quality of the research supported and to identify major outcomes arising from it; to consider whether the PMS Committee is currently funding the most appropriate areas of UK bioscience within its remit; and to identify ways to build on successes and address identified gaps and issues<sup>1</sup>.

The Panel's analysis was based on the results of questionnaire surveys of a sample of 155 current and past grantholders, 26 current and past Committee members, three other UK funding organisations, and on the final reports of a sample of 126 completed grants.

### KEY CONCLUSIONS

#### **1. The PMS Committee has supported a broad range of excellent science across its remit**

Overall, the research within the PMS Committee portfolio is of a very high quality. This is reflected in a variety of measures of success including final report grades, peer-reviewed research articles, publication citations, further funding to develop the research, training of researchers and their subsequent career development, new collaborations in the UK and overseas, development of intellectual property and the formation of spin-out companies.

#### **2. The Committee has supported some outstanding scientists working in the fields of plant and microbial sciences**

The highest quality research within the portfolio typically arose from individuals working in institutions with strong intellectual and capital infrastructure. These individuals have produced internationally significant discoveries that have ensured that the investments made by the Committee represented very good value for money.

#### **3. Committee support has enabled researchers to access a wide range of other funds**

The high quality of the research projects supported by the Committee has enabled researchers to access a wide range of other UK and international funds. The Committee has acted as an important connection between different funding agencies, and this has led to cross-boundary working and enabled researchers to broaden the impact of their research programmes. The PMS Committee and other UK funders have provided support that has contributed significantly to the strong international standing of the UK in plant and microbial sciences.

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<sup>1</sup> In addition to funding responsive mode grants, BBSRC funds research relevant to the PMS Committee remit via separate initiatives and via the core funding of some BBSRC-sponsored institutes. However, this funding is delivered independently of the PMS Committee and does not form part of this evaluation.

**4. The Committee has primarily supported basic research, with an appropriate balance of high-quality, innovative and incremental science**

The Committee has supported high-quality basic research across its remit and has not behaved in a risk-averse manner. It is important that the commitment to fund innovative and high-risk research is maintained.

**5. There is an opportunity to support more strategic and applied research through responsive mode funding**

The Committee's support for strategic and applied research within responsive mode was relatively limited. There are opportunities to build on the knowledge base provided by the high-quality basic research, by supporting more strategic research within the responsive mode portfolio. This includes ensuring that the findings from basic research in model organisms are translated to more strategic or applied systems. In particular, it is timely for discoveries made in *Arabidopsis* to be exploited in crops. The restructuring of BBSRC Research Committees should be used to promote and foster these changes, and it is essential that the remits of the new Committees reflect BBSRC's mission to support all types of research - basic, strategic and applied. Efforts must also be made to ensure that perceptions do not develop within the research community that particular Committees only support basic research.

**6. There are weaknesses in the provision of support and training in specific areas of the PMS Committee remit**

The PMS Committee remit is very broad and this inevitably meant that the portfolio could not cover all areas in sufficient depth. There were insufficient tools and resources available for microbiologists, especially for those working on non-model species. There were gaps in the training of new scientists, particularly in disciplines which focus on 'larger-scale' biological research at the organ or organism level. There was also a need to incorporate more training for 'softer', transferable skills within research projects and to increase the emphasis on the development of multi-disciplinary skill sets.

**7. The research supported by the Committee has delivered economic and social impacts**

Basic research supported by the Committee has underpinned advances in key areas of strategic importance to government and the UK, such as antibiotics and antimicrobials, bioenergy, biosecurity, emerging diseases of plants and animals, mitigating climate change, and sustainable agriculture. Research projects trained skilled, scientifically-literate personnel, many of whom went on to work in industry or the wider economy. Some researchers formed partnerships with industry and other organisations, exchanging knowledge and ideas, and ensuring that research was addressing the needs of a wider community of stakeholders. Public engagement activities helped improve awareness and understanding of plant and microbial sciences, and illustrated how BBSRC science is addressing issues of public interest such as 'superbugs' and climate change. Looking forward, many researchers believed that their research findings will ultimately benefit human health, the environment, or animal health and welfare.

**8. There is a need to promote greater links to other stakeholders who benefit from plant and microbial sciences research**

There are complex sets of stakeholders who benefit from the research supported by the PMS Committee. The scientific community faces a number of challenges and opportunities to ensure their research delivers greater impact to these stakeholders. There is a need to promote greater links to end-users, particularly those in industry and other funding agencies that support strategic research. More could also be done to address government priorities, contribute to government policy and engage with the public. BBSRC must assist grantholders by providing clear guidance of its expectations regarding the delivery of knowledge transfer and knowledge exchange. When developing grant applications, researchers should be encouraged to plan how their research project can deliver benefits to non-academic communities.

**9. BBSRC must continue to support excellent and creative investigator-driven science**

In the future, achieving the right balance of basic, strategic and applied research in responsive mode will be an exciting challenge which will require coordinated effort from BBSRC, its Research Committees and the research community. Funding of basic research is essential, and the serendipitous nature of scientific investigation means that such work can lead to exhilarating discoveries with unimagined impacts. Support for strategic and applied work is also important, and can similarly deliver excellent research and innovation. It is clear that scientific excellence will remain the key driver for funding all the types of research within BBSRC. In this respect, the high quality of the research within PMS Committee portfolio places UK plant and microbial scientists in a very strong position, and it is important to sustain and build on this success.

## CHAPTER 1. BACKGROUND

### Introduction

1. The Biotechnology and Biological Sciences Research Council is one of seven Research Councils sponsored through the Department for Business, Innovation and Skills (BIS) of the UK government. Its principal aim is to foster a world-class biological science community in the UK. The mission of the BBSRC is to fund internationally competitive research, to provide training in the biosciences, to encourage opportunities for knowledge transfer and economic impact, and to engage the public and other stakeholders in dialogue on issues of scientific interest.
2. BBSRC supports research in a number of ways, including research grants, studentships, fellowships, and strategic grants to BBSRC-sponsored institutes. In the 2008-09 financial year, 39% of BBSRC research funding (£164 million) was spent via the 'responsive mode' scheme, whereby research grants are awarded to unsolicited research proposals from eligible applicants in any area relevant to the mission of the Council. BBSRC also supports research through directed initiatives, where money is 'ring-fenced' to fund research grants that will deliver specific strategic objectives.
3. Researchers can receive support for basic, strategic and applied research projects through responsive mode:

Basic:	Research conducted for the advancement of knowledge
Strategic:	Research conducted with the expectation that it will form a broad base of knowledge likely to underpin the solution of recognised or expected current or future problems
Applied:	Research that is directed primarily at addressing a specific, practical problem or objective
4. For organisational purposes, the BBSRC research remit has historically been divided into seven key areas each covered by a Research Committee: Agri-Food; Animal Sciences; Biochemistry and Cell Biology; Biomolecular Sciences; Engineering and Biological Systems; Genes and Developmental Biology; and Plant and Microbial Sciences. In a restructuring exercise completed in 2008, the number of Research Committees was reduced from seven to four. The new Committees met for the first time in May 2009.

### Evaluation context

5. Evaluation is of growing importance to BBSRC and, with its emphasis on evidence based decision making, to the UK government. Evaluation plays a central role in:
  - justifying BBSRC funding allocation and contributing to the evidence that all Councils are required to submit to BIS
  - informing internal funding decisions, providing evidence of progress and achievement, and facilitating the development of a strategic overview for future funding decisions
  - enabling BBSRC to account to government, the public, the scientific community and other stakeholders for the funds it allocates
  - helping BBSRC to improve its policy and practice, through informing policy decisions and the design of new schemes, programmes and processes; and through identifying good practice, lessons learned, and ways to improve processes.

Formal evaluation of research is currently conducted at a number of levels in BBSRC:

- Project:      • Evaluation of final reports from grants
- Scheme:      • Evaluation of Research Committee responsive mode portfolios
- Evaluation of Research Initiatives (time-limited research funding in strategically significant areas), 2-3 years after the grants have ended
- Evaluation of funding schemes (e.g. New Investigator, international Partnering Awards, Research and Technology Clubs)
- Institution: • Institute Assessment Exercise, conducted every five years at the BBSRC-sponsored Research Institutes
6. BBSRC's Evaluation Strategy<sup>2</sup> outlines the Council's approach to evaluation and the methodology used. The responsive mode portfolios of individual Research Committees are evaluated on a rolling basis, whereby two Committee portfolios are evaluated every year. PMS is the sixth Committee portfolio to be evaluated, following evaluations of the Animal Sciences, Biochemistry and Cell Biology, Genes and Developmental Biology, Agri-Food, and Engineering and Biological Systems Committee responsive mode portfolios carried out between 2005 and 2008<sup>3</sup>.
7. This evaluation covers research grants supported in responsive mode through the PMS Committee which have been given a final report grade since 1996. The objectives of the evaluation were to:
- assess the quality and international standing of research funded through the PMS Committee
  - assess the economic and social impacts of research supported by the PMS Committee
  - identify the major outputs and, where possible, outcomes of the PMS Committee responsive mode portfolio over the past 10 years
  - identify strengths, weaknesses and gaps in the PMS Committee remit and the way it is structured
  - consult with the research community and other relevant bodies (government and non-government) to assess whether the PMS Committee is currently funding the most appropriate areas of UK bioscience within its remit
  - identify ways to build on successes, and ways to address identified gaps and issues.
8. BBSRC evaluations are evidence-based, and conducted by independent Review Panels comprising scientists not closely involved with the BBSRC. The expertise of each Review Panel covers the remit of the Research Committee being evaluated (for the PMS Committee Review Panel membership, see page 48). Review Panels are asked to provide an independent scientific evaluation of the evidence presented. For PMS this was:
- 126 sample final reports (representing 28% of all PMS Committee responsive mode grants that had been completed and graded at the time of sampling). See Appendix 1 for a list of sample grants (p.48).
  - Questionnaires returned by 83 principal investigators (PIs) of completed grants (representing 18% of all completed and graded PMS Committee responsive mode grants) and 72 current PIs (47% of all current PMS Committee grants that have been active for more than one year).

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<sup>2</sup> [http://www.bbsrc.ac.uk/organisation/policies/reviews/funded\\_science/bbsrc\\_evaluation\\_strategy.pdf](http://www.bbsrc.ac.uk/organisation/policies/reviews/funded_science/bbsrc_evaluation_strategy.pdf)

<sup>3</sup> The Biomolecular Sciences Committee was not included in this round of Research Committee portfolio evaluations. However, the non-structural biology aspects of the BMS Committee responsive mode portfolio were reviewed as part of a pilot evaluation. The methodology and lessons learned from the pilot evaluation formed the basis for subsequent evaluations of the other Committee portfolios. The structural biology supported by the BMS Committee has been reviewed extensively (e.g. BBSRC Review of UK Structural Biology).

- Final reports and questionnaire responses from seven PIs who had received significant support (£1.2 million - £2.2 million) from PMS Committee responsive mode over the evaluation period (55 grants, representing 8% of the funded portfolio)
- Questionnaires returned by 26 current and past PMS Committee members
- Questionnaires returned by the Department for Environment, Food and Rural Affairs, the Natural Environment Research Council, and the Wellcome Trust.
- Additional information about the grants funded through the PMS Committee responsive mode drawn from BBSRC databases.

## CHAPTER 2. STANDARD OF RESEARCH

### Summary

- The overall quality of the research within the PMS Committee responsive mode portfolio was very good, with many examples of internationally significant research
- The outputs that arose from the funded grants were very good and reflect the high standard of the research in the portfolio
- The highest quality research typically arose from gifted individuals working in institutions with strong intellectual and capital infrastructure
- The research funded by the PMS Committee made significant contributions to the UK's strong international standing in plant and microbial sciences
- The PMS Committee facilitated important connections between different funding agencies, resulting in cross-boundary working and enabling researchers to broaden the impact of their research

### Overview

9. The past ten years have been an exhilarating time for plant and microbial sciences, both internationally and within the UK. Extraordinary advances have been made as a new era of genomics has empowered scientists to address long-standing and novel biological questions with new technologies and resources. The PMS Committee has contributed significantly to enabling UK researchers to take advantage of these unprecedented opportunities. A programme of *Arabidopsis* research produced a step-change for plant scientists, fostering a new community of researchers conducting outstanding work in molecular plant science. Support for microbial sciences maintained a vibrant community of non-medical microbiologists, who took advantage of genome sequences and new genetic tools to make impressive breakthroughs in their fields. Moreover, the Committee supported a variety of exciting research projects that resulted in internationally significant work studying plant-microbe interactions and increased our understanding of plant health and disease. The Committee's support, working where relevant with other UK funders, has resulted in a highly productive period for plant and microbial sciences and has contributed to a strong international profile for UK research. The story of the research supported by the PMS Committee over the past decade is a tale of outstanding discoveries made by outstanding individuals and, if what's past is prologue, provides a tantalising glimpse of the even greater discoveries that are still to come.

### Research quality

10. The general standard of the research funded by the PMS Committee in the sample grants assessed by the Review Panel was very good. Many grants made substantial, internationally-significant advances in their respective fields and some were of exceptional quality.

11. 82% of the final reports on PMS grants, submitted within three months of the end of the award, were graded either A or B by PMS Committee assessors<sup>4</sup>. 32% of final reports received an A grade, which was impressive. This high level of performance was reflected in the sample of grant final reports reviewed and the observation that the majority of sample grants met their original objectives.
12. Of the 126 final reports reviewed by the Panel, 40 grants were identified as being particularly successful (32%). Summaries of these are given in Chapter 5, pages 38-43. There were numerous measures of success within the highlighted grants. These went beyond publishing papers in high-ranking journals, and grants were often noted for a combination of factors. Research was highlighted for being particularly innovative or pioneering at the time, opening up a subject area for other researchers, providing tools and resources for the community, obtaining further funding to develop more strategic aspects of the work, industrial relevance, developing intellectual property, or successfully engaging with the public. The Panel also identified a number of additional notable grants (pages 44-45). Some of the research supported by the PMS Committee formed the basis for current systems biology work and there is potential to develop this further in the future. Other research highlighted links with animal systems, an area that will become increasingly relevant.
13. There were some common elements amongst the grants that produced the highest quality research. They tended to come from more established research groups, especially those with a critical mass of staff and other funded projects. The most successful PIs often had a strategic vision for their research programme, matching their research interests to the opportunities available from multiple funding streams and agencies. In addition, these groups were able to take multiple approaches to address biological questions and had a greater tendency to network with other scientists.

## Research outputs

### Summary

14. The high standard of the research within the PMS Committee portfolio was demonstrated by the quality of outputs arising from the sample grants. There were many papers published in high quality peer-reviewed journals, a good number of staff trained and wide-ranging tools and technologies developed for the scientific community. In addition, there was a significant number of new UK and international collaborations, substantial further funding to develop the research, support for early-career researchers to establish new research programmes, the development of intellectual property and the formation of spin-out companies.
15. Data on research outputs from completed grants were collected from final reports and questionnaire responses for the sample of 126 PIs. However, it should be noted that figures are likely to be underestimates because while they include data from the final report forms for all 126 PIs, they only include survey responses for the 83 PIs who returned the questionnaire.

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<sup>4</sup> Reports are given a grade from A-D. The definition of these grades is as follows:

A: Very high class work that has produced results of considerable scientific importance in a cost-effective way and met all or almost all of the agreed or related key objectives.

B: Work that has significantly added to knowledge in the field and met the majority of its agreed or related key objectives.

C: Work that has fallen short of the contribution to knowledge or cost effectiveness expected from the original proposal even though it may have met some or all of its agreed or related key objectives.

D: Work that has not added significantly to knowledge in the field and/or has failed to address the agreed or related objectives.

## Publications

16. A total of 526 original research articles in refereed journals are known to have been published and reported so far from the completed and current sample grants. The median number of original research articles per completed grant was three, rising to four when review articles were included. This is in line with the level of published outputs from the evaluations of BBSRC's other Research Committee portfolios.
17. The Panel was impressed by the quality of the journals in which publications appeared, a view strongly endorsed by the international Panel members. The Panel identified a list of high ranking multi-disciplinary journals and prestigious journals in the field of plant and microbial sciences<sup>5</sup> (for details see p. 46). 58% of original peer-reviewed articles from completed and current grantholders were published in these journals and an impressive 4% of grantholders published original research articles in the multi-disciplinary journals 'Nature' or 'Science'. This was excellent, as it is challenging for any scientist to publish in these journals and research within the PMS Committee remit is not necessarily considered 'fashionable' by the journal editors.

*Researchers at the John Innes Centre received support from the PMS Committee to investigate the response of bacteria to nitric oxide. Nitric oxide is produced at high concentrations by specialised human cells known as macrophages to poison engulfed bacteria or tumour cells, and bacteria have evolved special mechanisms to protect themselves against its toxic effects. The research discovered that nitric oxide interacts directly with a bacterial regulatory protein to activate the expression of genes involved in nitric oxide detoxification. The findings were published in a range of high-impact journals, including 'Nature'.*

*Researchers at the University of Manchester conducted research into the structural basis of cell division in trypanosomes, microbial organisms that cause a variety of diseases including sleeping sickness in humans. When a trypanosome divides, two daughter cells of similar shape are produced. The researchers showed that structural information in the old cell is used to influence the shape and form of the new cell. The findings were published in the high-impact, multi-disciplinary journal 'Science'.*

*A research project at the University of Leicester investigated light signalling between chloroplasts and the nucleus in the model plant Arabidopsis. The researchers studied how porphyrin IX, which is involved in far-red light responses, is used as a signal, and examined the role of a plastid-localised protein in signalling regulation. The results were published in several research articles in prestigious journals, including 'EMBO Journal', 'Journal of Biological Chemistry' and 'Proceedings of the National Academy of Sciences of the USA'.*

18. 33% of grants published just one or two original research articles, but the evidence indicated that the majority of these were in good journals and were well cited. Some of these grants were identified as research highlights, and some articles had very impressive citation records.

*A research project at The Sainsbury Laboratory (University of East Anglia) investigated mechanisms of plant disease resistance in Arabidopsis. Researchers identified a key component of disease resistance to the pathogen Peronospora parasitica. This internationally significant research produced two research articles, both of which were published in the 'Proceedings of the National Academy of Sciences of the USA'. Together, these articles have been cited over 350 times.*

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<sup>5</sup> In determining the list of journals the Panel noted that journal impact factors vary considerably across disciplines due to factors other than research quality.

19. In terms of international standing of plant science research, an analysis of European publications in ISI-indexed plant science journals between 1999 and 2005<sup>6</sup> ranked the UK very highly. England, Scotland and Wales were placed first, third and fourth, respectively, for citations per plant science article. England and Scotland also had higher citations per article than all other G8 countries. A comparable analysis of the twenty most cited countries in ISI-indexed microbiology journals between 1994 and 2004<sup>7</sup>, placed the combined output from England and Scotland second amongst the G8 countries with respect to citations per article, behind only the USA. These data indicate that plant and microbial science in the UK is very competitive internationally. Although this impressive UK performance is not wholly attributable to the support of the PMS Committee (see Chapter 4, p. 34), the Committee has undoubtedly played an important role in enabling UK researchers to conduct very high-quality, internationally significant research.
20. 35% and 4%, respectively, of publications arising from PMS Committee grants had international or industrial co-authors. The international figure was similar to the proportion of PIs who reported formal collaborations with international researchers. The industrial figure was slightly lower than the proportion of PIs reporting formal links with industry (see Chapter 3, paragraphs 58-64).

#### New contacts and collaborations

21. The research supported through the PMS Committee has played an important role in building strong research communities in the UK. Over half of PIs who responded to the survey established new or improved contacts with fellow academics in the UK. Approximately one third of PIs reported contacts that resulted in formal collaborations, leading to joint funding applications and/or joint publications. In addition, participation of plant scientists in the BBSRC-funded Genomic Arabidopsis Resource Network (GARNet)<sup>8</sup> programme has been very beneficial: GARNet is an exemplary model of providing community support.

*Researchers at the University of York collaborated with scientists at the University of Lancaster and the University of Durham to study stomata in Arabidopsis. Stomata are small pores on plant leaves that enable gas exchange, and their opening and closing must be tightly regulated to enable uptake of carbon dioxide whilst minimizing water loss. The research project exploited the York group's experience in 'chromosome walking' to clone three genes involved in the regulation of stomatal response to reduced atmospheric humidity. The cloning of these genes provided greater insight into this important area of science and helped to widen the scope of their collaborators' research programmes.*

22. Similarly, over half of PIs established new or improved contacts with overseas academics, and about one third reported contacts which resulted in a formal collaboration. 25% of grantholders reported new or improved contacts with researchers from other European countries and 12% reported contacts with researchers in the USA. A small number of contacts were also reported with researchers in Australia, Argentina, Canada, China, Japan, Mexico, New Zealand, Pakistan, the Philippines, South Africa and Thailand. The number of international collaborations provides additional evidence of the strong reputation of UK plant and microbial sciences within the international research community.

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<sup>6</sup> [http://www.lab-times.org/labtimes/issues/lt2007/lt01/lt\\_2007\\_01\\_38\\_40.pdf](http://www.lab-times.org/labtimes/issues/lt2007/lt01/lt_2007_01_38_40.pdf)

<sup>7</sup> <http://www.in-cites.com/countries/top20mic.html>

<sup>8</sup> The GARNet programme was funded as part of BBSRC's Investigating Gene Function Initiative. It has provided support and resources to UK *Arabidopsis* researchers, including those supported through the PMS Committee.

*Researchers at the Wellcome Trust Sanger Institute, University of Oxford and University of Birmingham sequenced the complete genome of the bacterium Pseudomonas fluorescens SBW25. Members of this species are commonly found in association with plants and are capable of promoting plant growth. The researchers initiated a collaboration with scientists in the USA who were sequencing another strain of the same bacterium. This enabled the research groups to maximise the data that could be acquired from comparison between the sequences, and also ensured sequence annotation was coherent between the two strains. The international collaboration subsequently developed to examine the induction of plant genes by P. fluorescens, adding value to the original project.*

23. The level of new and improved collaborations within the portfolio and the number of joint publications generated were good; collaborations benefitted individual research projects as well as PIs' wider research programmes. The extent of networking and collaboration within the UK was impressive, but more could be done to increase the level of international collaboration. There can be difficulties with obtaining funding for collaborative activities<sup>9</sup>, but to be productive international interactions do not necessarily require additional funding. The strengths of the PMS Committee portfolio provide particular scope to establish partnership links with developing countries to tackle global challenges such as environmental change and emerging diseases. In this respect, the recent interaction between BBSRC and the Department for International Development (DfID) to fund research projects contributing to sustainable agriculture in the developing world is a very welcome development.
24. New contacts and collaborations were also established with industrial researchers, both in the UK and overseas; further details of these contacts are given in Chapter 3 (p. 22).

#### Further funding

25. The broad range of research supported by the Committee meant that there was a variety of opportunities available to obtain further funding to develop research projects. It is noteworthy that 60% of the holders of completed grants received further funding to develop the research supported by their grant. Funding was received from many sources, including the PMS Committee, other BBSRC Committees, the European Union (EU), the Wellcome Trust, the Natural Environment Research Council (NERC), industry, the Royal Society, the Leverhulme Trust, and the Department for Environment, Food and Rural Affairs (Defra). 36% of grantholders received further funding from BBSRC, 16% from other UK funding agencies, and 14% from international funding sources.
26. It is clear that the PMS Committee has provided important connections between funding agencies, which has led to cross-boundary working and enabled researchers to broaden the impact of their research. It was significant that a third of PIs supported through the PMS Committee received funding from more strategically orientated funding sources such as BBSRC Agri-Food (AF) and Engineering and Biological Systems (EBS) Committees, Defra and industry, suggesting that they were looking to translate the knowledge from the basic research funded by the PMS Committee. PIs were also seeking to increase the impact of their research through funding applications to the Medical Research Council (MRC), the Bill and Melinda Gates Foundation and other charities (see Chapter 3).

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<sup>9</sup> BBSRC provides support for international exchanges through a variety of mechanisms including the International Scientific Interchange Scheme (ISIS) and Partnering Awards (with China, India, Japan and the USA). For further details see: <http://www.bbsrc.ac.uk/science/international/index.html>. It should be noted that BBSRC can only fund the UK-aspects of collaborative research. Support for the partner country must come from their government (which may be challenging for developing countries) or other funding agencies (such as DfID).

*Scientists at the University of Leeds conducted research into the genes that are involved in the interactions between nematode pests and plants. Every year, nematodes are estimated to cause £80 billion of damage to crops worldwide. This project identified nematode genes that are activated during the initial infection of plants, and used RNA interference technology to show that they are involved in the infection process. The researchers obtained further funding through the Agri-Food Committee to develop plants with sustainable resistance to nematode pests. They also received a Sustainable Agriculture Research for International Development Initiative grant, to exploit their findings in the development of nematode resistant plantain crops for African subsistence growers.*

*Researchers at the University of Newcastle upon Tyne investigated the bioremediation of the highly-toxic industrial pollutant selenate. They characterised a novel membrane bound selenate reductase from a bacterium present in contaminated drainage water. The project was successful in obtaining further funding from the EBS Committee. The current EBS Committee project has the long-term objective of bioengineering a thermo-stable selenate reductase for use in an enzyme based thermo-extraction bioremediation strategy.*

*A joint research project between the University of Nottingham and the University of Warwick revealed knowledge of an important new control step in the abscisic acid biosynthesis pathway in tomato. The findings have potential use in the development of crops with more efficient water usage. The researchers obtained substantial further support of over £1.7 million from other organizations, including Defra and an industrial partner, to pursue this strategic research direction.*

#### New products, processes, resources, tools and technologies

27. About one half of PIs reported that their grant had led, or could lead to, the development of new products, processes, resources, tools or technologies, similar to that reported by most other BBSRC Committee portfolio evaluations. The outputs varied widely but included methods, reagents, transgenic and mutant lines, constructs, libraries, genome sequences and software. The users identified were primarily other academic researchers both within the UK and internationally, but also included industrial researchers, biomedical researchers, plant breeders and biotechnology companies. The new tools and technologies were made readily available to the wider community via publication in peer-reviewed journals or in online databases. Most of them remain readily accessible and relevant.
28. The most accessible outcomes to the wider community were those that arose from larger “-omics” activities (e.g. genome sequences, databases and genetic resources). Although the initial investment in these resources was expensive, it delivered good value for money. Genomics resources have stimulated hypothesis-driven research across the PMS Committee remit and opened up important new areas of scientific investigation. The availability of freely accessible data drives open scientific enquiry, and it is important for data from genomics activities such as sequencing and transcriptomic analysis to be made publicly available as soon as possible. The Panel therefore welcomed BBSRC’s Data Sharing Policy<sup>10</sup>, which sets out the Council’s expectations relating to data sharing; all PIs seeking research grant funding from BBSRC must submit a statement on data sharing as part of their application.

*Researchers at the University of York, University of East Anglia and the Wellcome Trust Sanger Institute sequenced the complete genome of the bacterium *Rhizobium leguminosarum*. Rhizobia are important agricultural organisms, allowing many crops to be grown without nitrogenous fertiliser, an energy-expensive and potentially polluting agent. This research provided the sequence for a strain of the bacterium that is widely used by scientists, and is descended from a strain obtained from the roots of a pea plant in the UK.*

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<sup>10</sup> [http://www.bbsrc.ac.uk/publications/policy/data\\_sharing\\_policy.pdf](http://www.bbsrc.ac.uk/publications/policy/data_sharing_policy.pdf)

*A research project at the University of Leeds produced over 21,000 gene sequences from the moss Physcomitrella patens. There are few non-flowering plants with extensive sequence data, and therefore the 'Expressed Sequenced Tags' generated through this project provided important materials for the study of the evolution of gene function in land plants.*

29. The Panel noted that a wide variety of tools and resources are available for plant scientists as well as for researchers working with several model microbial species. However, in general, there are considerably fewer resources available for microbiologists, and in some areas, such as soil microbiology, more support is needed. This is limiting the progress of microbiology research and BBSRC might consider reviewing its current support for tools and resources developed for microbiologists<sup>11</sup>.

#### Intellectual property and spin-out companies

30. 7% of sample grants resulted in applications to secure intellectual property, with a further 6% of PIs planning this in the future. Of the 14 reported patent applications, three were licensed and one received income. This is similar to the level observed in the evaluations of other BBSRC Research Committee portfolios.
31. Grantholders reported that PMS Committee funding contributed to the establishment of four spin-out companies. This figure is higher than reported in all other BBSRC Research Committee portfolio evaluations with the exception of the Engineering and Biological Systems Committee portfolio, which is significantly more user-orientated. Another spin-out company was generated from the research of those PIs with significant support from the PMS Committee (see page 17), and PMS Committee support for *Streptomyces* genomic research had contributed to the development of a further two spin-out companies.

*Researchers at the University of Durham used knowledge from their basic research programmes to establish Creative Gene Technology Ltd. This company is exploiting new techniques in plant genomics and proteomics to develop strategic targets for the agrochemical and food industries, including oil yield in rapeseed and the identification of novel herbicide targets.*

*Research at the University of Sheffield identified a unique group of surface exposed proteins of the bacterium Staphylococcus aureus which are essential for the bacterium's survival. The researchers have formed the company ABSynth Biologics to help exploit these research findings, and in particular, explore the potential of the proteins to provide novel targets for vaccine or antibody treatments against the 'superbug' MRSA.*

32. The Panel noted that the pursuit of intellectual property rights can hinder research and innovation, rather than promote it. Applications for patent protection can often be made too early, when the intellectual property has limited value. This is illustrated by the very small proportion of patents that are ever licensed or receive income. Institutions and grantholders should think carefully about the best approaches for developing intellectual property rights: for example, it could be better for researchers to work with industry or other stakeholders to develop their intellectual property before seeking patent protection, ensuring that awarded patents had real value. Industrial Panel members commented that universities often have unrealistic expectations of their intellectual property, and this could be a barrier to the uptake of research findings by small and medium enterprises. In addition, in recent years, the proliferation of Material Transfer Agreements for

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<sup>11</sup> BBSRC is in the process of establishing a comprehensive database of tools and resources developed from BBSRC funding as part of a wider review of data sharing policies. This should enable a more accurate picture of the resources available to microbiologists to be developed.

exchange of basic biological materials has been an unwelcome development, creating additional bureaucracy over materials which have little likelihood of being commercially exploited.

33. Despite these reservations, the high standard of research across the PMS Committee portfolio meant that there was potential for greater development and exploitation of intellectual property than had been realised to date. Striking the correct balance between the free flow of information and the protection of intellectual property is challenging, but it is important that BBSRC promotes a culture where researchers are encouraged to develop and exploit their intellectual property, as appropriate.

### **Principal Investigators with significant funding from the PMS Committee**

34. The Review Panel examined the contributions to research outputs and outcomes from seven PIs who have received significant support (£1.2 million - £2.2 million) from the PMS Committee responsive mode funding over the evaluation period. It considered 39 final reports from 55 grants, which accounted for 8% of the portfolio funded during the period.
35. The standard of work produced by these PIs was impressive, and was generally of even higher quality than the majority of the other completed grants. The research led to highly-cited publications in high-ranking journals, as well as an impressive range of other outputs, including the development of tools and resources for the wider community and intellectual property. The decisions of the Committee to fund these grants were strongly endorsed and this research serves as a prime example of the value of responsive mode funding: PIs had defined research programmes with a clear direction and focus, which were sustained through competitive responsive mode funding applications.
36. There was evidence that the PIs' research groups were more involved with knowledge transfer and exploitation of their research findings than the wider sample of grantholders. For example, four of the seven PIs made applications to BBSRC's Follow-on Fund, a funding stream that supports 'proof-of-concept' work at the very early stage of turning research outputs into a commercial proposition, and three were successful. One of these awards contributed to the formation of a spin-out company. However, there was some concern that not all seven PIs were actively involved in the knowledge transfer of their research and, considering the degree of financial support received from BBSRC, more could be expected in this area.
37. The research grants represented excellent value for money and also added value to the PIs' wider research programmes. The PIs used a variety of funding models to support their research: some were heavily reliant on PMS Committee and other BBSRC funding, whereas others used mixed funding models, with BBSRC support representing less than a third of their research income. For researchers who had significant non-BBSRC funding, support from responsive mode grants had contributed to the critical mass of their research groups and enabled a broader range of research activities to be conducted. It is therefore highly likely that PMS Committee funding contributed to some of the impressive outputs and outcomes arising from the PIs' wider research activity. This group of PIs demonstrates the synergy between PMS Committee funding and other agencies and organisations, which was also observed within the wider portfolio of PMS Committee research grants.
38. The strength of the research conducted by these PIs highlights a general theme throughout the portfolio: the most successful research has arisen from outstanding individuals (both PIs and postdoctoral researchers), and these individuals were working in institutions with a strong intellectual and capital infrastructure. BBSRC and academic

institutions must provide adequate support for plant and microbial science research to ensure that such exceptional scientists remain within the UK and that the critical mass of excellent research groups is maintained.

### **Less successful grants**

39. Although the general standard of the research funded by the PMS Committee was very high, there was still some potential to improve research quality throughout the portfolio. The quality varied across the sample projects and some less competitive grants were funded. A small but significant number of grants were less successful than expected, either failing to meet their original objectives or resulting in little or no tangible output.
40. 12% of grantholders who had completed grants reported no original research articles arising from their project. This was disappointing, even though some failure is inherent to the nature of scientific investigation and the figure is in line with the performance observed in other Research Committee portfolio evaluations. The apparently unproductive grants came from across the PMS Committee remit, and the majority (87%) were from PIs who had not returned questionnaires to update their final reports. The grantholders included both established and less well-established researchers, although there was a bias towards less-experienced PIs. The median number of previous BBSRC research grants received by these researchers was one.
41. The most common reasons given by PIs who identified that their projects were less successful than anticipated were experimental, methodological or technical. In a small proportion of less successful projects, poor performance resulted from grants being naïve or unrealistically ambitious at the outset. However, in the main, limited success in meeting objectives was an inevitable consequence of conducting creative, innovative or high-risk research. It should be expected that researchers using novel or state-of-the-art technologies, or tackling challenging questions will encounter some problems; if no researchers experienced any experimental difficulties, it would be a clear indication that the portfolio was too conservative and risk-averse.
42. In some grants, difficulties were encountered with recruiting staff with the appropriate training or experience. There were also problems with the retention of Research Assistants (RA), which were often a major contributing factor to poor performance. Poor career development prospects and lack of employment stability for RAs are particularly relevant to staff retention, and therefore directly impact on grant performance. Although the majority of grants awarded by the PMS Committee were for 36 months, the median length of employment for a postdoctoral research assistant was 28 months.
43. Several projects changed direction owing to developments from other research groups (e.g. publication of new data). This is inevitable, and most grantholders showed flexibility and initiative to agree new priorities with BBSRC. Projects in which significant changes were made were often as productive as projects that went as planned.
44. BBSRC should ensure that it fosters an environment where researchers feel able to report significant problems with their research and agree new project objectives. This may be particularly important for less-experienced PIs who may not have the confidence to report issues until it is too late to change the direction of the project.

## Final reporting

45. A final report submitted three months after a grant ends is not a particularly effective way to identify outputs, as this is too early for many major outputs to have arisen. The Panel welcomed the proposed RCUK Outputs and Outcomes Collection System, which will be designed to capture these data annually both during and after the grant, to provide more reliable evidence for evaluation purposes, but noted that it will be essential to ensure PIs enter their outputs into the system.
46. There was some over-reporting of outputs, particularly publications, within final reports. Some sample PIs reported outputs that appeared to be primarily supported through funding sources other than the grant in question. There was also notable variation in the quality of the final scientific reports. The majority of reports failed to set the work in a broader context, hence understating the degree to which the work was tackling fundamental problems or how it was addressing BBSRC strategic objectives. The importance of the results was often reported as providing the opportunity for further research, rather than the solution to a problem. In addition, the lay summaries in some reports were poorly written.
47. The sample final reports failed to capture the extent to which the Committee supported high-risk research within the portfolio. Systems should be adjusted to address this issue, with PIs being asked to complete a risk/reward profile about their grants. It is important that the benefits of funding less-conservative research projects are identified and celebrated.

## CHAPTER 3. RESEARCH IMPACTS

### Summary

- The research funded through the PMS Committee is of interest to wide and complex sets of stakeholders
- The training and skills development of researchers was a significant impact of PMS Committee funding and contributed to the wider economy
- The level of interaction with industry was appropriate given the basic nature of the research portfolio, but more should be done to encourage an increased level of interaction in the future
- The research funded through the PMS Committee had economic and social impacts
- The basic research supported by the Committee underpinned advances that support key government priorities in areas such as antibiotics and antimicrobials, bioenergy, biosecurity, emerging diseases of plants and animals, mitigating climate change, and sustainable agriculture
- There are now significant opportunities to deliver greater impact from the portfolio of high-quality research, and it is timely to make a step-change in this area

### Overview

48. The research supported by the PMS Committee is primarily basic in nature. Nevertheless, it is of broad interest to complex sets of stakeholders and provides benefits to many groups of end-users. The research within the PMS Committee portfolio has impact beyond the supply of high-quality scientific research to the knowledge base, and has contributed to the UK economy and the wider public good. Research projects trained skilled personnel who conduct research and work within the wider economy. The knowledge from research findings was transferred to stakeholders in industry and elsewhere, and led to the production of patents and the formation of spin-out companies. In addition, research projects underpinned advances that are addressing key government priorities such as antibiotics and antimicrobials, biosecurity, bioenergy, emerging diseases of plants and animals, mitigating climate change and sustainable agriculture.
49. This Chapter examines how PMS Committee grantees are addressing the needs of stakeholders. In particular, the following sections describe the impact of PMS Committee research in training and skills development, support for early-career researchers, interactions with industry, knowledge exchange, public engagement and longer-term economic and social benefits.

### Training and skills development

50. Training of postdoctoral researchers and PhD students is a vital function of BBSRC funding. It provides the skilled scientists who conduct research, as well as contributing scientifically-literate personnel to the wider economy. 76% of PIs reported an increase in the skills base of their research group as a result of their grant. The majority of completed grants employed one RA, with a small number of grants employing two or three RAs. 96% of RAs worked full time on the project. Technicians were employed on

66% of completed grants. Altogether, this represents a significant skill base in plant and microbial sciences.

51. The training and skills development provided by the grants was good, and was reflected in the high quality of scientific outputs arising from individual projects. 12% of RAs obtained permanent academic positions as either their first or second destination after the grant<sup>12</sup>. This is a notable achievement: the skills and expertise development were enabling and the RAs were competitive in the employment market. In addition, 18% of RAs moved into the private sector, industry or commerce, 11% obtained government or other public sector positions, and 4% entered the teaching profession.
52. There was an adequate number of PhD students being trained within the plant and microbial sciences, although there were specific shortages in certain areas (see Chapter 4, paragraph 100). 66% of completed grants had PhD projects running at the same time on topics associated with the research grant. There was evidence that studentships running alongside research grants added significant value to some grants and, in some cases, the most significant outputs of the grant were dependent on the student's contribution<sup>13</sup>. The association of studentships with research grants could also provide excellent training opportunities for the student, as well as providing access to resources that were not otherwise available, given the low consumable budgets of individual studentships. BBSRC could take further advantage of these synergies by funding studentships that are directly associated with individual research grants. Final reports should also be amended to capture information on associated studentships. Currently, final reports only record information on the training of staff that are funded by the research grant itself and provide no details on student training.
53. BBSRC should encourage universities and other institutions to take a more professional approach to the training and skills development of RAs and PhD students. This needs to include the development of higher-level transferable skills, such as communications and project management, as well as technical competence. Moreover, the lack of a systematic mechanism to track postdoctoral researcher and student careers through the academic environment is a significant weakness in evaluating the effectiveness of the training provided by Research Councils, universities and other institutions.
54. Although the quality of training and skills development within the projects funded by the PMS Committee was generally high, there were wider problems with the retention of trained individuals within the research environment. Retention has been recognised as a major issue in several areas of the biosciences in recent years and has contributed to skills shortages. The Panel felt that this was primarily related to the scientific career structure and the comparatively low salaries paid to researchers at all levels. Problems with staff retention were a major factor associated with poor grant performance. Short term contracts of three years or less do not encourage staff retention, and the emerging practice of institutions employing RAs for less than the duration of the grant award is exacerbating this problem. More support also needs to be given for researcher mobility to ensure key skills developed during student and postdoctoral training are retained and used effectively.
55. The Panel noted that there are gaps in undergraduate training within the plant and microbial sciences. In particular, there is insufficient training for undergraduates in microbiology. This is a concern as microbiology underpins a large proportion of the BBSRC research base. There is also insufficient emphasis on plant and microbial sciences in the school curriculum. A lack of appropriate skills among school and

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<sup>12</sup> This figure is likely to be an underestimate as it includes RAs who are still employed at their first destination after the PMS Committee grant, as well as RAs where the second destination after the grant was unknown or not provided. If these RAs are removed from the sample, the figure rises to 23%.

<sup>13</sup> For example, the student had made a significant contribution to the main publication arising from the grant.

undergraduate students will have negative impacts on the recruitment of high-quality PhD students and postdoctoral researchers in the future. Although training in schools and at the undergraduate level do not fall within the remit of the PMS Committee, they are within the interests of BBSRC. Through RCUK, BBSRC supports a number of mechanisms to make science accessible to young people, including encouraging greater involvement of researchers in schools and in the bodies that influence the school curriculum, but there could be scope to do more.

## Support for early-career researchers

56. There are opportunities within PMS Committee responsive mode funding for early-career researchers to establish themselves in academia. This is important, as new investigators often inject fresh and exciting ideas into the portfolio and are essential to the long-term health of the research community. The Panel highlighted several grants that had enabled early-career researchers to build independent research programmes, including a number of BBSRC New Investigator (NI)<sup>14</sup> grants. However, there was evidence that the Committee could do more to support new researchers. The PMS Committee had the lowest success rate for NI applications of all the Research Committees and was funding fewer NI grants relative to its size than other Committees. For example, the PMS Committee funded 8% of all BBSRC NI grants between 2003 and 2007, which is lower than the proportion of all BBSRC responsive mode grants funded by PMS during this period (13%).

*A New Investigator grant at the University of Glasgow aimed to develop an integrated view of potassium nutrition in Arabidopsis plants by investigating gene expression using microarrays. Potassium is an essential macronutrient for plants, and its supply in the field impacts on crop yield and nutritional quality. The project helped the researcher establish a productive research programme, and led to further funding from BBSRC.*

*A research project investigating the role of aquaporins in the regulation of water supply to growing leaf cells helped establish the academic career of a researcher at the University of Paisley. The project led to further funding from BBSRC and the Leverhulme Trust.*

57. Funding for three years is not sufficient to establish a sustainable research programme, and BBSRC may wish to consider different funding structures for new researchers. For example, five year funding schemes may be more appropriate with the final two years dependent on a progress review at the end of the third year. Such '3+2' schemes are used in France and Germany to support new researchers.

## Interaction with industry

58. New or improved contacts with industry in the UK were reported by 12% of sample PIs, and 8% of PIs reported similar contacts overseas. 5% and 4% of PIs established new formal collaborations with industry in the UK and overseas, respectively. 13% of PIs received financial support from industry, either at the outset of the project or subsequently to develop the work. The majority of this funding was through CASE

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<sup>14</sup> The New Investigator scheme is aimed at university lecturers and researchers at BBSRC and NERC institutes, within three years of their first appointment. Its purpose is to assist those individuals to obtain their first research grant. Applications are judged against the same criteria as other responsive mode proposals, but research potential rather than track record is taken into account.

studentships<sup>15</sup>, but grantholders also received support from industry through the LINK scheme or Industrial Partnership Awards (IPA). The level of interaction with industry was reasonable, given the basic nature of the research that accounts for the majority of the portfolio.

*Researchers at Aberystwyth University and the University of Manchester received an Industrial Partnership Award to investigate proteins that resuscitate dormant mycobacteria. These bacteria include Mycobacterium tuberculosis, the causative agent of tuberculosis (TB). Dormant TB is able to persist in the body and is resistant to antibiotic treatment. The findings from this project contributed to potential targets for novel TB vaccines.*

*A LINK project provided support for researchers at Rothamsted Research to examine how plant cell wall enzymes interact with synthetic man-made chemicals, such as herbicides. The research identified an enzyme with a key role in detoxification, and the results were made available to the industrial partner to assist with their crop protection chemical discovery programme.*

*A LINK project provided support for scientists at the University of Cambridge to investigate the plant cell cycle, the process which a cell undergoes in order to divide. The researchers used a multi-tool approach to examine a complex set of interacting gene expression patterns among cell cycle regulators. A collaboration agreement was signed between the University and the industrial partner governing any future exploitation of the work.*

59. The high quality of the basic scientific research within the PMS Committee portfolio provides a strong bedrock of knowledge of which a significant proportion is of potential use to end-users in industry. Over the evaluation period, the interaction of researchers with industry had a relatively narrow focus, concentrating on a few key areas such as plant disease protection or the development and production of antibiotics. However, the research supported by the Committee could make important contributions to industry across a large number of other strategically important areas, including bioenergy, biomaterials, bioreactors, bioremediation, diagnostics, diet and health, fermentation, microbial inoculants, pharmaceuticals, pesticides, plant breeding, renewable materials, sustainable agriculture, and vaccine development.
60. Several grants produced scientific knowledge that was exploitable by the wider community, but in many cases PIs chose not to pursue such opportunities. It was not clear whether this was due to a lack of interest from PIs or whether the barriers to industrial or commercial interactions were too high. Some researchers could have been more imaginative in broadening the impact of their PMS-funded research, and it was disappointing that PIs had not sought more in-kind support from industry and other organisations (for example using growth facilities in industry or agricultural faculties to support research on species other than *Arabidopsis*).
61. However, it should be noted that much of the industrial interaction in the plant and microbial sciences is driven by research that falls within the remit of BBSRC's AF and EBS Research Committees. Over the evaluation period, 32% of all researchers funded through the PMS Committee responsive mode also received support from the AF or EBS Committees. This was encouraging as it was likely that some of these researchers were using the PMS Committee to support research that underpins more strategic elements or their research programmes.
62. The limited size of the plant science industry within the UK is a barrier that inhibits plant and microbial scientists from increasing the level of interaction with that sector. In

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<sup>15</sup> Collaborative Awards in Science and Engineering (CASE) allow students to receive high quality research training in collaboration with an industrial partner. Students spend a period of between 6 and 18 months working with the company, and the company makes a financial contribution to the costs of the project and the training of the student.

particular, public concern within Europe over the use of genetic modification technology has contributed to a significant decline in the UK plant science industry. It is vitally important that the UK retains a strong research base in the plant and microbial sciences, to ensure that the existing industry remains in the UK and as an incentive to encourage new industry to invest in the UK.

63. The Panel noted that industry also places a high value on quality basic research, a view strongly endorsed by the industrial Panel members. In this respect, the research funded by the PMS Committee has made an essential contribution to the knowledge base that underpins UK industry.
64. There were several examples of the commercialisation of research outputs within the portfolio and in PIs' wider research programmes. 9% of all PIs funded by PMS Committee responsive mode during the evaluation period made applications to the BBSRC Follow-on Fund (FoF), and 3% were successful. The Panel noted that the technology management company Plant Bioscience Limited, which has been partly funded by BBSRC, has made an important contribution to furthering the exploitation of research by PMS Committee grantholders, as had other university-based technology transfer offices. Overall, it was encouraging that PIs were engaging in the commercialisation of research outputs, and it is important that BBSRC provides support to PIs to incorporate this type of activity into their research programmes.

*Researchers at the John Innes Centre and The Sainsbury Laboratory (University of East Anglia) have used the findings from their research programmes to establish Norfolk Plant Sciences Ltd. This company is using transgenic technology to develop blight-resistant nutritionally enhanced potatoes. A key part of the initial work is being funded through BBSRC's Follow-on Fund.*

## **Knowledge exchange**

65. There are further opportunities for knowledge exchange from the PMS Committee portfolio. For example, there is significant scope to transfer the findings from basic research with model organisms to more applied or strategic systems, bringing the research closer to needs of other funding agencies and end-users.
66. About one quarter of sample PIs reported some knowledge transfer of the research supported by their grant to more strategic or applied biological systems. In addition, about half of all PIs supported by the PMS Committee over the evaluation period had, as part of their wider research programme, obtained some funding from sources that support strategic or applied research. Although the general level of knowledge transfer within the funded projects was limited, it should be noted that knowledge transfer was not an essential objective of responsive mode research during the evaluation period. It is now important to demonstrate a step-change in this area and it is timely, for example, to increase the focus on transferring the high-quality knowledge generated from basic plant science research into *Arabidopsis* to crop species. It would also be worthwhile to increase the use of UK-specific crop species in research.
67. Encouraging knowledge exchange between researchers and end-users is not solely the responsibility of BBSRC. Other organisations and end-users must help by informing researchers of their strategic aims, and by providing appropriate opportunities and incentives for researchers to explore knowledge exchange activities; the knowledge of the applied problems end-users are attempting to solve that is gained through these exchanges is very valuable. BBSRC-funded researchers must also recognise their obligations to ensure that relevant publicly-funded science, with benefits for society and the economy, is more explicitly recognised and used.

68. The main driver for Higher Education Institution funding is the Research Assessment Exercise (RAE)/Research Excellence Framework (REF), with the majority of universities' financial support for research coming from quality-related research (QR) funding. There is currently an opportunity for BBSRC to work with the Higher Education Funding Council for England (HEFCE) to increase the role of knowledge exchange in the Funding Council reward system. However, changes to university funding mechanisms could create new challenges for the PMS community. They may prove beneficial for researchers who can interact with medical and pharmaceutical industries, but damaging to other areas, such as agricultural research, where very few UK-owned large companies remain within the UK.

## Public engagement

69. The public is an important stakeholder in the research supported by the PMS Committee. As a result, there is a need for scientists to engage with the public, to inform people about complex scientific issues, to understand and address current and emerging attitudes to bioscience research, and to make a compelling case for the public funding of research. BBSRC requires all PIs, or a member of their group, to conduct public engagement activities as a condition of their grant. PIs report on their activities in their final report, but these aspects are not subject to formal evaluation.
70. The majority of grantholders funded by the PMS Committee was involved in public engagement during the course of their grants. There was participation in a wide range of activities, including shows, open days, public dialogue events, school visits, publicity in non-scientific media, and responding to media inquiries. These activities were conducted by PIs and the postdoctoral researchers from their groups. There was, however, evidence that the definition of public engagement was not universally understood by researchers: some PIs reported activities which do not constitute public engagement, such as departmental websites, articles in scientific journals, and UCAS recruitment days.

*Researchers at the University of Nottingham investigating how the microscopic parts of bacterial flagellar motors interact to make them work were very active in presenting their work to schools. The Research Assistant participated in the Researchers in Residence Scheme, and was based in a school for one week. The researchers also presented a practical demonstration on bacterial swimming at the Leicester Science Learning Centre to school technicians. In addition, the researchers made many other presentations to school pupils, school teachers and school technicians explaining the molecular genetics of bacteria.*

*Researchers at the University of Bath established a 'Café Scientifique' in Bath. Café Scientifiques provide an opportunity for the public to explore the latest ideas in science and technology. An expert speaker gives a short talk on a particular topic, and this is followed by questions from the audience and a general discussion. The meetings are informal and accessible, and provide the opportunity for members of the public to discuss their views with the speaker.*

71. There was significant involvement by grantholders with activities in schools, covering a range of age groups, with the majority based around talks and lectures. There was also a limited number of activities that included significant 'hands-on' practical elements. These were very valuable, and concentration on activities with a practical focus in the future would be very helpful. There was evidence that researchers were hosting Year 12/13 students and first year undergraduates in their research groups to conduct work experience, which was encouraging. There are wide-ranging benefits from the interactions between researchers and schools, including making science accessible to young people and inspiring them to consider scientific research as a career.

72. A significant proportion of the public engagement carried out by researchers was opportunistic or responsive, rather than pro-active. PIs had used agricultural shows, British Association for the Advancement of Science (BA) Festivals, 'Science Week', and university or institute open days. Many PIs also had responded to media enquiries. While the degree of responsiveness is heartening, the Panel would have welcomed more evidence of PIs initiating and developing their own public engagement activities.
73. PIs who developed activities that could easily be re-used were often very active in public engagement, delivering the same activity to many audiences. Researchers have to balance many competing demands in their work, and the time needed to develop public engagement activities is a major barrier to researchers' participation. This could be addressed by establishing a web-based repository for resources, enabling researchers to incorporate material developed by others into their own public engagement activities.
74. Approximately 20% of grantholders reported no public engagement activity in their final reports, which was disappointing. The lack of any involvement by a significant proportion of grantholders highlights an important issue with BBSRC's policy on public engagement: the requirement for grantholders to conduct public engagement activities cannot be fully effective if there is no sanction against PIs who fail to meet their obligations. The Panel also noted that BBSRC offers no incentives, rewards or professional recognition for conducting public engagement activities, and it is likely that researchers' involvement has been driven primarily by personal interest and the culture within grantholders' institutions rather than BBSRC. It is important for BBSRC to clarify whether it regards PIs' participation in public engagement as a serious grant condition. If so, it must ensure that there are sanctions against grantholders who do not comply.
75. Learned societies often have very good public engagement programmes. In particular, the Society for General Microbiology has a range of excellent materials and advice available on its website. BBSRC should encourage researchers to participate in the public engagement programmes of these societies, as well as with other organisations, such as National Science Learning Centres or RCUK.
76. Encouraging a culture of public engagement amongst researchers must begin early in scientific careers. PhD students and postdoctoral researchers should receive training in scientific communication, learning how to relate complex issues to a general audience. There was a lack of accessible, non-scientific literature for the lay public in the grantholders' reported public engagement activities, and increased training may help address this. It was pleasing that 25% of sample PIs attended a media training course.
77. PIs are not required to discuss the specific research conducted during their grant as part of their public engagement activities. This is appropriate, as different people have different interests and priorities, and it is important that scientists interact with the public on general issues of scientific interest. Nevertheless, the Panel felt that there were potential benefits in researchers explaining the specific details of their own research to the public, such as justifying their individual research programmes to the wider community and building confidence in the research that BBSRC funds.

## Economic and social impacts

78. Economic and social impacts relate to the overall objectives of BBSRC as a funding body, and are generally expected to arise in the longer-term. The following ultimate impacts (relating to the objectives in the BBSRC ten-year vision) might arise from BBSRC support for plant and microbial sciences through responsive mode funding:
- research findings are used for the 'public good' e.g. medical research, advances in biotechnology, government policy
  - exploitation of research brings income to the research community and broader economic benefit to the UK e.g. from new technologies, intellectual property, spin-out companies, etc.
  - the UK maintains high international standing in plant and microbial sciences research
  - BBSRC maintains its role as a key funder of plant and microbial sciences research in the UK
  - public confidence in UK plant and microbial sciences research is maintained.
79. These impacts relate to how effectively BBSRC is functioning and delivering the impact expected of publicly funded research, and it is therefore very important that they are identified and, where possible, attributed to BBSRC funding. It is recognised that measurement and attribution of these impacts is difficult and imprecise.

### Contributions to the public good

80. The support provided by the PMS Committee contributes to the public good in a number of ways; it:
- trains scientists in basic research; provides the next generation of scientists as well as scientifically literate personnel who have gone on to work in the wider economy
  - provides a bedrock of fundamental knowledge that underpins future research, commercial and other applications, and helps shape government policy
  - helps maintain a vibrant higher education sector that contributes to the economy; foreign students are attracted to work in UK universities with exciting and dynamic research environments
  - contributes to public engagement with science, and supported science of public interest (e.g. 'superbugs', climate change)
81. An essential part of BBSRC's mission is to contribute to the UK's knowledge based society by ensuring new knowledge is generated. The high standard of research within the PMS Committee portfolio demonstrates that BBSRC is meeting this obligation. The research supported by the PMS Committee provides the knowledge for meeting future challenges, both expected and unexpected, and the expertise and skill base to exploit this knowledge. Over the evaluation period, the basic research supported by the PMS Committee has underpinned advances in key areas of strategic importance to government and the UK, such as antibiotics and antimicrobials, bioenergy, biosecurity, emerging diseases of plants and animals, mitigating climate change, and sustainable agriculture.
82. Scientific research often requires time before the impacts are realised. Nevertheless, there are examples of research within the portfolio that have already made a significant contribution to the public good:
- Research into proteins that resuscitate dormant mycobacteria, including the causative agent of tuberculosis (TB), has been incorporated into the AERAS Global

- TB Vaccine Foundations vaccine development programme. AERAS has taken an exclusive licence to the grantholder's intellectual property for these purposes.
- Research into the bacterium *Staphylococcus aureus* has provided potential for new vaccine and antibody treatments against the 'superbug' MRSA. The findings are being taken forward through the spin-out company ABSynth Biologics. The market for a vaccine against *S. aureus* is estimated to be worth \$2 billion by 2020, and nearer to \$3 billion for an antibody treatment.
  - Basic research on plant viruses contributed to the ground-breaking discovery of a class of small RNA molecules that 'silence' the expression of other genes. The findings were subsequently shown to have important roles in other organisms including humans, and have opened the door for other scientists to discover specific RNAs involved in cancer, heart conditions and viral infections. These RNA molecules are also used routinely as tools by other researchers
  - Research that improved the understanding of the resistance risk in key plant pathogens to commercially important Quinone outside inhibitor (QoI) fungicides has contributed to the improved use and durability of these fungicides.
83. Looking forward, 42% of sample PIs stated that their research has the potential to make contributions to the public good; 20% thought that their research will benefit the environment; 13% felt their research could contribute to human health; 6% identified benefits to animal health and welfare; and 3% cited potential to contribute to government policy or meeting other government priorities.

#### UK standing in plant and microbial sciences research

84. The PMS Committee is the primary funder of molecular plant science and a vital supporter of non-medical microbiology within the UK. A significant proportion of the portfolio is of international standing as demonstrated by the quality of research outputs and metrics comparing publication citations between countries (see Chapter 2, p. 13). It is clear that the research funded through the PMS Committee has significantly enhanced the standing of UK plant and microbial sciences internationally. The Committee's support, together with that of other UK funders, has contributed to UK research being highly regarded internationally. This view is reinforced by the significant number of international researchers who have chosen to collaborate with researchers supported by the PMS Committee.
85. Several factors may help explain the international strength of UK plant and microbial sciences research. The UK has centred its research activities on a relatively limited number of key species, and this focussed approach has strengthened research communities and enabled rapid progress to be made. The funding system in the UK is less bureaucratic than in some other European agencies, and this reduces the barriers for researchers seeking support to pursue exciting research directions. UK researchers also have the scientific freedom to address their own research objectives. A combination of researcher independence and stability in funding provides the best environment to conduct the highest quality research.

#### **Delivering greater impact from research**

86. There is an increasing need for UK researchers to demonstrate the wider impacts of public funding of research to government and other stakeholders. Over the evaluation period, the PMS Committee has supported an impressive range of high-quality basic research that has benefitted the UK. Researchers have developed skills and provided training; they have developed and exploited intellectual property, formed links with industry, transferred knowledge to end-users, translated the findings from basic

research to applied or strategic biological problems, underpinned research conducted by other funding agencies, promoted public understanding of science, contributed to government policy and addressed key government priorities.

87. There are opportunities for the strong base of basic research supported by the PMS Committee to deliver even greater impact to UK society, and it is timely to demonstrate a step-change in this area. Scientists have a responsibility to help realise wider benefits from their research findings and to think more carefully about how curiosity-driven research programmes might address needs of other stakeholders. High-quality basic research should remain a cornerstone of BBSRC research funding, and it was clear that the greatest impacts within the portfolio have been founded in excellent science. However, researchers must also recognise that scientific excellence and strategic relevance are not mutually exclusive.
88. A large number of stakeholder groups benefit from the research supported by the PMS Committee. It is unlikely that individual researchers will be able to interact with all groups of stakeholders, nor would it be appropriate for them to do so. However, it is important that all researchers seek to broaden the impact of their research or to identify explicitly the potential benefits. In parallel, BBSRC must be clear about its expectations regarding the delivery of knowledge transfer and knowledge exchange, and must ensure that the research community understands how this will be incorporated into the assessment of research grant applications.
89. To date, the delivery of impact within the majority of responsive mode research projects has involved relatively little planning or management. The effectiveness of identifying increased impact from research funding could be improved by incorporating coherent plans for knowledge exchange within grant applications, at the outset. Activities to increase the impact of research should be planned and costed, and then funded as part of the grant award. At the end of a grant, the success in meeting the plan's objectives should form part of the assessment process.
90. BBSRC must ensure it provides the appropriate support for grantholders and Committees to enable them to demonstrate increased impact of BBSRC-funded research. Wider involvement of the non-academic research community in Research Committees could be beneficial, although in the past it has been difficult to attract these individuals. The new Committee structure may reduce the commitment required from individual Committee members and consequently facilitate the recruitment of more industrialists and other stakeholders.

## CHAPTER 4. BALANCE AND COVERAGE OF THE PORTFOLIO

### Summary

- The overall coverage of the PMS Committee remit by the funded grants was good
- The balance between plant and microbial sciences was appropriate and reflected the number of applications received from each area
- The Committee primarily supported basic research
- There was evidence that the research community viewed the PMS Committee as supporting basic research, and had therefore not submitted applications for strategic or applied work
- The research supported by the PMS Committee was complementary to those of other funders, although there are gaps between organisations that prevent the impact of research being fully realised

### Overview

91. Since its inception, the role of the PMS Committee has been to support integrative studies of physiology and biochemistry to gain an understanding of the way in which plants and microorganisms function in both terrestrial and aquatic environments.
92. The overall coverage of the PMS Committee remit by the funded grants was good. The remit is very broad and it was noteworthy that the Committee had been generally successful in allocating funding across the remit. However, the breadth of the remit inevitably meant that the portfolio could not cover all areas with sufficient depth and there was evidence that some aspects of the remit were insufficiently addressed over the past ten years. The funded grants had all been within the remit, although a few were surprisingly narrow and it might have been more appropriate for these to have been funded by another BBSRC Committee.

### Coverage of the portfolio

93. The balance between plant and microbial sciences in the portfolio was appropriate and reflected the number of applications received from each area. The interface between plant and microbial science (e.g. plant-microbe interactions) benefitted considerably from the structure of the Committee, and it was important that these interactions were not at the expense of either of the individual disciplines. In future, new and emerging technologies will provide significant opportunities for truly integrative research between plants and microbes, and it is important that these synergies are not lost in the Committee restructuring exercise.
94. The Committee had primarily supported basic research within the portfolio. Supporting basic research is an essential part of BBSRC's mission and funding for creative, investigator-driven, basic science must be maintained; the serendipitous nature of scientific investigation means that such work can lead to exciting discoveries with unimagined impacts. The high quality of the basic research funded by the PMS Committee also provides an opportunity to deliver research with greater strategic

impact. Although the quality of research proposals must always remain the primary criterion on which funding decisions are made, there is scope to improve support for strategic and applied work within responsive mode funding. Researchers should also be encouraged to think more carefully about how basic research can be more closely aligned with addressing strategic objectives. There were many cases of high-quality basic research within the portfolio that could have delivered greater strategic impact with relatively minor changes to the research project.

95. It was apparent that the research community views the PMS Committee as supporting basic research, and therefore they had not submitted applications for more strategic or applied work. This perception needs to be addressed, as the Committee can only fund strategic work if it receives high-quality proposals. BBSRC's mission is to promote and support high-quality basic, strategic and applied research relating to the understanding and exploitation of biological systems. However, the description of the PMS Committee remit does not provide a clear indication that the Committee supports strategic and applied research. BBSRC's Committee restructuring exercise provides the opportunity to address this issue, and to ensure that the principle for support of all types of research, basic, strategic and applied, is enshrined within the remit of the new Committees. The new Research Committee B (Plant, Microbes, Food and Sustainability) will bring together research from the PMS Committee and AF Committee remits, and this should be used to encourage researchers supported by the PMS Committee to increase the strategic relevance of their science. However, it is important that this is not at the expense of the strategic focus of research from the former AF Committee.
96. High quality basic, strategic and applied research funded by BBSRC can be identified through a range of outputs and outcomes that it delivers. The publication of research articles in high impact journals is a measure of international excellence for basic research; other outputs are equally valid for identifying high quality strategic and applied research. Research Committees must ensure that they recognise all types of excellent research, and user relevance and the potential economic and social impacts of research should be explicit criteria in the assessment of applications.
97. The Committee had achieved an appropriate balance of high-risk, innovative research and high quality, incremental developments within the portfolio, and had not behaved in a risk-averse manner. In the future, there is a concern that financial pressures and falling application success rates across BBSRC could make all Research Committees more conservative and less inclined to fund more risky research. It is important that a commitment to fund innovative and high-risk projects within responsive mode funding is maintained.
98. As indicated above, some areas of the PMS Committee remit were not covered adequately in the portfolio over the evaluation period. These included: bacterial morphogenesis, bacterial structures, biohazardous bacteria (such as MRSA), fungal physiology, industrial microbiology, marine microbiology, metagenomics, unculturable microbes, photosynthetic/primary carbon metabolism, plant breeding, plant-invertebrate interactions, and soil/rhizosphere biology. BBSRC must also ensure there is adequate support for genomic activities, especially as the Wellcome Trust Sanger Institute will no longer sequence plant genomes.
99. Apparent gaps in the responsive mode investment may be addressed by funding from other BBSRC Research Committees, Research Initiatives, and Strategic Grants made to BBSRC research institutes, particularly at the John Innes Centre, Rothamsted Research, and the former Institute of Grassland and Environmental Research (IGER)<sup>16</sup>.

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<sup>16</sup> During the evaluation period IGER was a BBSRC sponsored institute. The site at Aberystwyth has subsequently joined with the Institute of Rural Sciences and Biological Sciences at Aberystwyth University to become the Institute of Biological, Environmental and Rural Sciences (IBERS), managed by Aberystwyth University.

For example, over 80% of responsive mode applications within the area of soil science are submitted to the AF Committee, and this area is also supported by BBSRC through the Sustainable Soil Function (SoilCIP) Institute Strategic Programme Grant, based at Rothamsted Research, that will receive funding of £15 million over five years.

100. Several disciplines where there were shortages in the number of skilled staff were apparent: bacterial physiology, microbial ecology, virology, crop science, plant breeding, plant-invertebrate interactions, plant virology, and whole plant physiology. In general, these disciplines focus on 'larger-scale' biological problems at the organism or organ level. Over the evaluation period, there has been a drive towards investigating cellular and molecular biological mechanisms, stimulated by the use of new '-omics' technologies. Research at the organism level has not been investigated to the same extent with these modern technologies, and may be regarded as less attractive or 'old-fashioned' by the universities and other institutions. However, a lack of trained scientists in these areas will create problems in the future. There was also a need for greater emphasis on bioinformatics and multi-disciplinary training. About one third of sample PIs reported some difficulty with staff recruitment, including difficulties finding a qualified individual, accepting someone with less experience than required, or that there were no suitable UK candidates for the position. Staff recruitment was a particular problem when a project required an RA to use multiple skills.
101. The lack of Committee input into the allocation of studentships was a weakness with the current system and was partially responsible for the failure to address the gaps in specific areas of the remit and in multi-disciplinary training. In addition, researchers at many institutions that receive substantial BBSRC funding are unable to bid for studentships, and this has resulted in missed opportunities for training and research.
102. The Panel noted the severe lack of trained plant breeders within the UK and agreed that this situation needs to be addressed urgently. The existing skill base is disappearing rapidly, at a time when agricultural challenges are increasing and the availability of plant breeders is of growing strategic importance. Although training new plant breeders is primarily the responsibility of the plant breeding industry, BBSRC supports research that underpins developments in plant breeding. The Panel welcomed the fact that, as part of its Crop Science Initiative, BBSRC is funding targeted priority studentships to develop a new cohort of crop researchers, trained in plant molecular biology as well as crop genetics and breeding, who will be able to bridge the gap between plant and crop science. The lack of plant breeders is a worldwide problem, and the UK needs to do more to ensure its own needs will be met in the future.
103. The Committee had acted professionally and fairly in its assessment of proposals and allocation of funding. However, there was some evidence that insufficient representation for specific areas of research on the Committee had influenced the portfolio coverage. For example, relatively few projects had been funded in the theme of 'Photosynthesis, respiration and partitioning of resources', despite a relatively large number of applications in this area. This may be related to insufficient expertise in plant physiology on the Committee. It was also apparent that the community had fixed perceptions about which aspects of the remit were most likely to receive funding, and that this has resulted in a low number of applications in some areas. BBSRC must ensure the whole scientific community is aware of the opportunities that are available from its Committees across its entire remit. In addition, the Panel urged all researchers working within the PMS Committee remit to submit applications in their areas of strength, to avoid such perceptions becoming a self-fulfilling prophecy.
104. The division between the PMS Committee and other BBSRC Research Committees, and in particular the AF Committee, was clear to the community. However, there were some areas that spanned Committee remits, with soil science a notable example, and

the Panel felt that this was not ideal. There are opportunities within the current BBSRC Committee restructuring exercise to provide greater integration of plant and microbial sciences funding. For example, providing greater coherence to funding opportunities in microbial science and removing potential issues where areas of plant science sit between the remit of the PMS and AF Committees. BBSRC must avoid any further dilution of the microbial science community during Committee restructuring.

105. The number of responsive mode applications to the PMS Committee has been declining over recent years. A higher proportion of PIs obtained subsequent funding from other BBSRC Committees than from the PMS Committee, suggesting that PMS-funded researchers are seeking support from other BBSRC Committees. This is the opposite of the observations from all other BBSRC Committee portfolio evaluations, where a higher proportion of PIs obtained further funding from the original funding Committee than from other BBSRC Committees.
106. As was the case in other portfolio evaluations, the role and importance of Priority Areas in the PMS Committee remit was unclear. There was evidence that the scientific community did not understand how Priority Areas were determined or how they affected funding decisions. The Panel therefore welcomed BBSRC's withdrawal of Committee Priority Areas as part of the Committee restructuring exercise. They will be replaced with a smaller, focussed list of Council-wide strategic priorities that cut across the whole BBSRC remit.
107. Over the evaluation period, the research funded by the PMS Committee has supported researchers working on a variety of organisms. There has been a focus of activity on a limited number of key species, including several model organisms. Given limited resources, this was appropriate. However, the focus of activity has had some unwelcome consequences. In particular, whilst the strong support the Committee provided to the *Arabidopsis* community has been very beneficial, it inevitably resulted in some important areas of crop science being overlooked. In recent years, BBSRC has made significant efforts to address this issue, which is welcome.

## Multi-disciplinary research

108. Multi-disciplinary science involves research that crosses between traditionally separate disciplines, such as biology, chemistry, mathematics or physics. In an analysis of all seven BBSRC Research Committees, PMS was ranked fourth with twenty multi-disciplinary grants live on 1 April 2007 (8% of all multi-disciplinary grants). This analysis is based on the PI's or co-PI's department, and will be an underrepresentation of the true figure<sup>17</sup>. The majority of multi-disciplinary grants were with chemistry departments, although there were also collaborations with computing, engineering, mathematics, and physics departments. The Panel noted that more multi-disciplinary research would add further value to the portfolio.
109. Although more support was needed for multi-disciplinary research, the Panel noted that the PMS Committee supported a variety of projects where postdoctoral researchers received broad training across biological sub-disciplines. This was particularly the case for the work on plant-microbe interactions, which was a clear strength of the portfolio.

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<sup>17</sup> This metric is not an ideal way to capture multi-disciplinary research, but is a working definition that enables data to be fairly easily extracted from BBSRC grant database, and analysed.

## Overlap with other funders

110. The PMS Committee is the primary source for funding molecular plant science within the UK, and is an essential source of funding for basic microbiological research. However, several other organisations fund research that potentially overlaps with the research funded by the PMS Committee, and these funders have made vital contributions to the success of plant and microbial sciences research in the UK. Defra, the Gatsby Foundation, NERC and the Scottish Government are key funders of UK plant and microbial science, and MRC and the Wellcome Trust are important funding agencies for microbiology. These funders were invited to comment on potential gaps and/or overlaps between their organisation and BBSRC's PMS Committee.
111. The strengths of other funders of research in the PMS Committee area were complementary to those of BBSRC. No significant areas of inappropriate overlap were identified between BBSRC and other funders, and where small overlaps existed the Panel felt that these were important to ensure that there were no gaps in funding. The research funded by PMS Committee through responsive mode grants supports the basic end of the research spectrum, which underpins the work of other funding bodies. This has been most widely realised through the provision of trained personnel and the dissemination of knowledge through high quality scientific publications. Other forms of knowledge exchange have been relatively limited to date.
112. The interfaces between BBSRC and other Research Councils were largely satisfactory. However, the fragmentation of microbiology funding across Research Councils was an issue for microbiologists. Panel members mirrored the concern of the PMS Committee that the MRC had reduced support for microbiology research, and this has limited the opportunities for microbiologists within the UK. The Panel noted that these issues were exacerbated by divisions within the microbial community itself, and in particular the failure of microbiologists to speak with a united voice.
113. NERC did not identify any gaps in cover, but noted that there was potential overlap between remits when research on plants or microbes is relevant to natural environments and ecosystems. However, the boundaries between the remits and responsibilities of both Councils were well defined and understood by the research community.
114. There were notable gaps in cover between BBSRC and some other funders, in particular between BBSRC and Defra. Whereas BBSRC research was at the basic end of the spectrum, Defra funding was heavily weighted towards strategic work, and there could be gaps in the 'research pipeline' between the organisations. Defra felt that there were several areas within the PMS Committee remit that needed more support: environmental and climate challenges (especially resource use efficiency in respect to nitrogen fertiliser, pesticides and water), crop science, root physiology, pesticide resistance, modelling of interactions between plants and other organisms, renewable materials, and remote sensing for crop management. In addition, Defra endorsed a shift from model organisms to crops, and felt there should be a greater emphasis on integration of aspects of the PMS remit.
115. It is important for BBSRC researchers to contribute to narrowing the gaps in the overall 'research pipeline' between Research Councils and other organisations that support more strategic research. There are several examples of good practice adopted by scientists in the UK, which are helping to address these issues. For example, the UK-Brassica research community and the MONOGRAM Network are addressing the ways to support end-user needs, for UK-grown brassicas and cereals, respectively. The Genomic Arabidopsis Resource Network (GARNet) has also enabled closer collaboration between the *Arabidopsis* community and scientists working with other

model species and crops. These networks could serve as good models for other research communities.

116. The gaps between the basic research supported by BBSRC and the end-user focus of other organisations are barriers to the potential benefits and impact of BBSRC-funded research being widely realised. Greater links between organisations are needed to bridge these gaps, which will require more linked strategic thinking between funding bodies.

### **Summary of gaps and weaknesses within the PMS Committee portfolio**

117. Although the standard of research, research impact, and coverage within the PMS Committee portfolio was very good, there were several areas where the Panel identified gaps and weaknesses. The following text summarises the issues raised throughout the report. It should be noted that many of the issues cannot be addressed by BBSRC, but should be recognised by universities and other institutions.

- |                                 |  |
|---------------------------------|--|
| Standard of research            | <ul style="list-style-type: none"><li>• A small proportion of grants were less successful than expected</li><li>• The primary causes of underperformance were experimental, technical and methodological reasons, or staffing difficulties</li></ul>   |
| Tools and Resources             | <ul style="list-style-type: none"><li>• There are insufficient tools and resources for microbiologists, especially for those working with non-model species</li></ul>  |
| Intellectual Property           | <ul style="list-style-type: none"><li>• Inappropriate pursuit of intellectual property rights could hinder research and innovation, rather than promote it</li></ul>   |
| Training and skills development | <ul style="list-style-type: none"><li>• There were gaps in the training of researchers and PhD students, notably in disciplines which focus on 'larger-scale' biological research at the organ or organism level</li><li>• There is a need for training in 'softer' transferable skills, such as project management and communications</li><li>• Short term contracts of three years or less do not encourage staff retention, and the emerging practice of employing Research Assistants for less than the duration of the grant award is exacerbating this problem</li><li>• The lack of Committee input into allocation of studentships had contributed to gaps in training in certain disciplines as well as multi-disciplinary research</li><li>• There is no mechanism available to track the scientific careers of PhD students or postdoctoral researchers</li><li>• There is insufficient emphasis on plant and microbial sciences within university and school curricula</li></ul> |

Support for early-career researchers	<ul style="list-style-type: none"> <li>• The PMS Committee had a lower success rate for New Investigator research grant applications than all other Research Committees</li> <li>• The three year funding provided by New Investigator grants is not sufficient to establish a sustainable research programme</li> </ul>
Interaction with industry	<ul style="list-style-type: none"> <li>• There was scope for greater interaction with industry within the portfolio</li> <li>• The interaction with industry had a relatively narrow focus, despite the potential of the research to make contributions to industry across a large number of areas</li> </ul>
Knowledge exchange	<ul style="list-style-type: none"> <li>• The level of knowledge transfer within the portfolio was limited</li> <li>• It is timely to increase the focus on transferring high-quality basic plant science research from <i>Arabidopsis</i> to crop species</li> </ul>
Public engagement	<ul style="list-style-type: none"> <li>• 20% of grantholders had not conducted any public engagement activity, despite this being a condition of grant funding</li> <li>• The requirement for grantholders to conduct public engagement activities cannot be fully effective if there is no sanction against PIs who fail to meet their obligations</li> </ul>
Economic and social impacts	<ul style="list-style-type: none"> <li>• There are opportunities for the strong base of basic research supported by the PMS Committee to deliver even greater impact to UK society</li> <li>• The delivery of impact within responsive mode research projects has involved relatively little planning or management</li> <li>• All researchers should seek to broaden the impact of their research or identify explicitly the potential benefits</li> </ul>
Coverage of the portfolio	<ul style="list-style-type: none"> <li>• The breadth of the PMS Committee remit inevitably meant that the portfolio could not cover all areas with sufficient depth</li> <li>• There are opportunities to increase support for strategic research within the responsive mode portfolio, building the high-quality basic research supported by the Committee</li> <li>• There was a perception within the research community that the Committee would only support basic research, and this had probably affected the number of applications submitted for strategic or applied research</li> <li>• Perceptions had developed within the research community about which areas of the remit were most likely to be funded, and this probably reduced application submissions in certain areas</li> <li>• In a few cases, insufficient representation for specific areas of research on the Committee had possibly influenced the portfolio coverage (e.g. photosynthesis)</li> <li>• There were gaps in cover between BBSRC and some other funders, in particular between BBSRC and Defra</li> </ul>

## Final Reporting

- A final report submitted three months after a grant ends is not a particularly effective way to identify a grant's output and outcomes
- There was over-reporting of outputs, particularly publications, within final reports
- Final reports failed to set the work in a broader context, hence understating the degree to which the work was tackling fundamental problems or how it was addressing BBSRC strategic objectives
- The lay summaries of reports were often poorly written
- Final reports did not capture the extent to which the Committee supported high-risk, innovative research within the portfolio
- Final reports did not capture the contribution associated PhD student projects had made to the research, or the contribution research projects had made to student training

## CHAPTER 5. RESEARCH HIGHLIGHTS

### Research highlights from completed responsive mode grants

#### *A complete genome sequence of Pseudomonas fluorescens*

*Pseudomonas fluorescens* encompass a diverse group of bacteria found in a wide range of terrestrial and aquatic habitats. Members of the species are commonly found in association with plants and are capable of promoting plant growth. The project sequenced the genome of *Pseudomonas fluorescens* SBW25 and a megaplasmid originally isolated from this strain. The genome sequence is available online and complements the published sequence from another strain of the same bacterium. During the project, the researchers established a collaboration with scientists in the USA who were sequencing the PfO-1 strain of *P. fluorescens*. This enabled both research groups to maximise the data that could be obtained from comparison between the sequences, and also ensured sequence annotation was coherent between the two strains. The international collaboration subsequently developed to examine the induction of plant genes by *P. fluorescens*, adding value to the original project.

#### *An analysis of chloroplast-nuclear signalling using aplastidic guard cells in Arabidopsis*

Although the majority of proteins in a plant cell are encoded in the nucleus, in photosynthetic cells many nuclear-encoded proteins are targeted to photosynthetic plastids or chloroplasts. This New Investigator grant examined the intracellular signalling between the plastid and the nucleus by exploiting mutants that lack plastids in specific cell types, which suggested that plastids produce a signal that is able to pass between cells through plasmodesmata. The research resulted in a notable publication that has been well cited by other researchers.

#### *Assembly of infectious bluetongue virion from cDNA clone*

Bluetongue virus is a double stranded RNA virus and an important animal pathogen. It is one of the few viruses in which mutations are unable to be introduced by genetic techniques. The project aimed to develop a reverse genetics system for this virus (manipulating cDNA). Despite expressing all 10 of its genes in mammalian cells it was not possible to synchronise their assembly. Six peer-reviewed articles were published – two in the high-profile journal 'PNAS'. There was also a good amount of public engagement, nationally and internationally

#### *Characterisation of a nitric oxide responsive transcription factor*

Nitric oxide (NO) is a key molecule used as a defence against bacterial infection. It is sensed by the bacterial cell leading to a global stress response. Using parallel *in vivo* and *in vitro* approaches the activator of this response was shown to be generally inactive due to a C-terminal domain with a non-haem iron center which masks the ATPase catalytic center. NO binding induces a conformational change uncovering the catalytic site resulting in transcription activation of the network. This work resulted in several publications in good quality journals.

#### *Control of fimbriation in E. coli in response to alanine, leucine, nitrogen and stress*

Fimbriae are used by bacteria to adhere to one another and to animal cells. This research analyzed molecular mechanisms of the reversible ON/OFF switching in the production of type 1 fimbrial adhesin in the context of the protein-DNA and protein-protein interactions, which generate either stimulative or antagonistic effects. This research also tried to highlight the physiological significance of this genetic circuit by investigating the effects of the amino acid and nitrogen status on gene expression in *E. coli*. The work was published in good quality journals that included 'PNAS'. The unique regulatory system described by this research would serve also as a good model and tool in systems biology and synthetic biology.

#### *Coupled translation termination and re-initiation of overlapping open reading frames*

This research identified a novel translation process called coupled translation. It occurs when a ribosome finishes the translation of the first protein, moves back towards the 5' end of mRNA and then translates a second protein in a human respiratory virus. This process is common to all pneumoviruses. Surprisingly, this research showed that a *cis* element, which is 150 nucleotides away from the translation start site, controls this coupled translation process. The findings were very exciting, demonstrating that a simple system, such as a virus, embeds very sophisticated gene expression machinery.

*Disarming the glucosinolate-myrosinase system in the cabbage aphid – consequences for tritrophic interactions*

The cabbage aphid is a serious pest of brassica crops such as commonly grown cabbages and oilseed rape, and it spreads viral diseases to these crops. This research used a chemical approach to investigate methods of interfering with the aphid defence mechanisms. The work provided insights into interactions between plant, aphid and aphid predators such as ladybirds, and showed how the aphid's glucosinolate-based defence impacted on ladybird fecundity. The work also generated industrial interest.

*Elucidating signalling pathways in plant K homeostasis on the basis of gene expression patterns*

Potassium (K) is an essential macronutrient for plants, and its supply in the field impacts on crop yield and nutritional quality. This New Investigator grant aimed to develop an integrated view of plant potassium nutrition, and the research examined potassium signalling pathways by investigating gene expression by microarrays. The results showed that K-starved plants mount a constitutive defence response against herbivores. The findings were of international significance and had potential applications for plant breeders in disease resistance. The project also resulted in a large number of refereed papers.

*Excision and insertion of pathogenicity islands in *Pseudomonas savastanoi*: the *avrPphB* model*

Bacteria secrete effector proteins directly into plant cells, some of which are encoded by avirulence genes that can activate resistance responses in the plant. This work studied the evolution of virulence in a bean pathogen, in particular by examining a chromosomal region (pathogenicity island) containing an avirulence gene. The research provided a molecular explanation of how exposure to resistance mechanisms in plants drives the evolution of new virulent forms of pathogens. This was an exciting and focussed study, which resulted in a publication in the high impact journal 'Current Biology'.

*Expressed sequence tags for homologous recombination in the moss *Physcomitrella patens**

The project produced over 21,000 expressed sequence tags from the moss *Physcomitrella patens* (and nearly 1,700 from another moss, *Ceratodon purpureus*). There are few non-flowering plants with extensive sequence data, and therefore this project provided important materials for the study of the evolution of gene function in land plants. The project was very productive: there were several good publications, including one in 'Science'; extensive data-sets were deposited in public databases; fruitful links were developed with UK and international academic research groups; materials have been provided to industrial partners; further funding obtained from a charitable foundation; and there was active involvement in public engagement activities.

*Functional analysis of a novel disease resistance signalling gene, *EDS1*, in *Arabidopsis**

This research used genetic analysis to identify a central regulatory component of disease resistance to *Peronospora parasitica* in *Arabidopsis*. The *EDS1* gene was cloned and characterised, and this led to the cloning of a second gene involved in plant defence. The work is of international importance, and resulted in two papers in the high-ranking journal 'PNAS'. In addition, the research resulted in two patents, and increased links with industry, including an industrial CASE studentship.

*Functional analysis of transposon-tagged gametophytic fertility genes in *Arabidopsis**

Plant fertility and seed production are of vital importance both in the natural environment and for crop plants in agriculture. This research characterised the function of five genes important for pollen fertility, and identified biological roles in anchoring proteins to the pollen cell surface, modification of surface-associated polysaccharides, and pollen tube growth. The research was basic in nature but also had a strategic relevance, and resulted in papers in high-ranking journals.

*Functional dissection of bacterial and chloroplast protein translocation mechanisms using GFP imaging*

This research focused on the twin-arginine translocator protein transporter, responsible for exporting proteins out of the bacterial interior. The researchers developed and used a very effective non-invasive method using fluorescent reporter proteins to follow protein transport *in vivo*. This resulted in exciting details on the distribution of the transport apparatus on the bacterial cell membrane and showed a surprisingly high mobility of the separate parts of the translocation machine. The work resulted in a number of good publications and the resources generated in the grant are now used by many other researchers.

*Identifying and characterising the function of novel guard cell signalling genes*

Stomata are small pores, mainly at the base of plant leaves, which enable gas exchange. This research cloned three genes that are involved in the regulation of stomata opening by atmospheric relative humidity, and implicated abscisic acid in this regulation. The work resulted in a publication in the high impact journal 'Current Biology'. This was a side project for the group that carried out the work, but it opened up this important area of research to others.

*Light regulation of glutamyl-tRNA reductase – the first committed step of chlorophyll synthesis*

Chloroplast development requires the coordinated synthesis of the chlorophylls and chlorophyll-binding proteins that comprise the light harvesting complexes of the chloroplast. This research focussed on how light regulates the first committed step of chlorophyll synthesis through different photoreceptors, and identified a role for PhyA in plastid-nuclear signalling. This was a grant from an early-career researcher, and the research produced a series of well cited papers in good journals.

*Light signalling and intercompartmental communication between chloroplasts and the nucleus*

This research addressed the question of how porphyrin IX, which is involved in far-red (FR) light responses, is used as a signal for communication between plastids and the nucleus. For this the AtABC1 ATPase protein and gene was analyzed. It was shown that the protein functions as a homodimer and acts by interacting with other proteins. The results were published in high-ranking journals, including 'EMBO Journal' and 'PNAS'.

*Mechanisms of ripening control through ethylene signalling and gene regulation*

Ethylene is an important plant hormone involved in fruit ripening and as well as other biological processes such as senescence and the response to pathogens. This research aimed to improve the understanding of the perception, signalling and genetic responses to ethylene, using tomato as a model crop plant. The research used an integrated approach to elucidate a system with complex and unexpected regulation, and resulted in excellent science published in good journals. Furthermore the PI engaged extensively in communication with the media and the wider public on the sensitive issue of genetic modification, leaving very positive messages.

*Microbial selenium cycling: characterisation of a novel membrane-bound selenate reductase*

Selenate is a highly toxic industrial pollutant that can present a significant hazard to human health. One of the most successful ways to clean selenate contaminated areas is through bioremediation using microorganisms. This research used a combination of approaches to characterise a novel membrane bound selenate reductase from a bacterium present in selenium contaminated drainage water, and resulted in a large number of publications in high ranking journals. The work was followed up with further funding from the BBSRC Engineering and Biological Systems Committee.

*Molecular basis of sporophytic self-incompatibility*

Self-incompatibility is the most important mechanism that prevents fertilization in hermaphrodite flowering plants. This project identified a novel *Senecio squalidus* stigma-specific plant peroxidase (SSP). SSP was not the female determinant in self-incompatibility, but did point towards a role for reactive oxygen species in pollen-stigma interactions. The research provided new opportunities for plant breeders interested in plant reproduction, and resulted in a good number of publications. The Principal Investigator also received funding for a BBSRC Science Week Award to make the work accessible to the public.

*Molecular identification of the genetic loci responsible for suppression of resistance in wheat*

Yellow rust is a major fungal disease that affects wheat. Research from this Industrial Partnership Award generated wheat mutants with enhanced resistance to yellow rust, and developed additional tools for studying rust resistance in wheat. The work was strategic in nature, and the findings were published in 'Molecular Plant-Microbe Interactions', a journal that does not normally published applied research of this type. The project had a tangible impact, and resulted in further funding from the EU and an industrial CASE studentship.

*Nitrate reduction to ammonia by fermentative bacteria: major new roles for the periplasmic nitrate and nitrite reductases*

This project aimed to understand why enteric bacteria retain two biochemically and genetically independent pathways for nitrate reduction. The research combined expertise in the areas of microbial physiology, molecular genetics, biochemistry and electrochemistry, and was successful in meeting all of the initial objectives, as well as others. The research resulted in fourteen peer-reviewed papers, some in high-impact journals. The PIs were also actively involved in public awareness of science particularly through work with local schools.

*Orchestrating cell cycle, cell growth and differentiation in Arabidopsis: the roles and targets of E2F transcription factors*

The processes which a cell undergoes in order to divide are termed the cell cycle. This LINK project examined the role of the E2F genes in cell cycle control and how they integrate with the processes of proliferation, cell growth and differentiation. The research used a multi-tool approach to examine a complex set of interacting expression patterns among cell cycle regulators. The work was published in good quality journals, generated industrial interest and a good network of collaborators. There was also significant outreach activity from the group during the grant.

*Protein targeting and mobility in the plant secretory system*

The research aimed to tag and track proteins in the plant secretory system. This project was the first to target GFP to the Golgi apparatus, with the results suggesting targeting systems for Golgi are similar to mammalian systems. There were also unique studies on regulation of ER to Golgi transport in plants. The work was internationally very significant, and produced a high number of publications in good quality journals.

*Regulation of a calcium channel in relation to polarised growth of root hairs*

This project demonstrated the role of calcium channelling in root hair plasma membranes in regulating the calcium gradients causing polarised apical extension. During the course of the work it was discovered that root hair growth was associated with and required the production of reactive oxygen species. This finding led to work, not originally envisaged in the proposal, which characterised the interactions between the cellular production of reactive oxygen species and cell growth, as mediated via calcium channelling. This resulted in a highly cited paper in the journal 'Nature'.

*Revealing structure/function relationships of a high affinity nitrate transporter, Nrt A, by site directed mutagenesis*

The way in which a whole array of substances pass through the outer barrier of living cells is a major topic in biology and medicine. This research provided valuable insights into understanding the structure and function of the NrtA nitrate transporter, an important membrane protein that has been actively studied for 60 years. The researchers took advantage of comparative genomics to identify conserved amino acid residues. A combination of site-directed mutagenesis and biochemical analysis were then used to identify important residues for NrtA function. The research resulted in a number of publications in good journals, including the high impact journal 'PNAS'.

*RNAi as a basis for defining both nematode and plant genes involved in compatibility and to provide novel control*

Every year worldwide, nematodes are estimated to cause about £80 billion of damage to crops. This project identified genes that are activated in nematodes during initial infection of plants. RNA interference of the expression of some of these genes was associated with lower establishment of nematodes in plant roots, and also produced male-biased sex ratios compared with untreated nematodes. Plant genes activated after nematode infection were also identified. The work resulted in several good publications and intellectual property that may be used to develop commercial crops with increased resistance to attack by nematodes. There was also excellent public engagement, with the work being presented at several public events.

*Role of reactive oxygen species in stress-induced signalling for APX2 gene expression in Arabidopsis*  
The *Arabidopsis* APX2 gene encodes an ascorbate peroxidase, a key component of cellular antioxidant defences. This research project identified hydrogen peroxide as the main reactive oxygen species for the induction of APX2 gene expression under light stress conditions. The results showed that this induction was restricted to bundle sheath cells in the leaf vasculature, and that there was a strong relationship to leaf water status. The results led to a drastic adjustment to the picture for light stress control through APX2.

*Salicylic acid and hydrogen peroxide in abiotic stress acclimation in plants*

Improved environmental adaption in crops would extend growing seasons and geographical limits, while reducing losses due to the increasing temperature variability caused by climate change. This research focussed on the role of salicylic acid and hydrogen peroxide in temperature stress acclimatisation in plants. Analysis of transgenic tobacco lines revealed salicylic acid to be a factor in signalling pathways between heat and disease responses, and new evidence was produced of hydrogen peroxide as a signal in heat tolerance. The research resulted in publications in good journals, as well as an industrial collaboration and further funding from the BBSRC Agri-Food Committee.

*Sequencing the genome of Rhizobium leguminosarum*

Rhizobia are important agricultural organisms, allowing many crops to be grown without nitrogenous fertiliser, an energy-expensive and potentially polluting agent. This aim of this research was to provide a fully annotated, publically available sequence of widely used strain of *Rhizobium leguminosarum*. The sequenced genome was found to comprise a circular chromosome of 5Mbp and six plasmids. The sequence data were made publicly available, although full annotation was completed after the end of the project. The grant also provided a focal point for several researchers, enabling networks to develop and spurring more wide-ranging collaborations in the UK *Rhizobium* community.

*Sexual reproduction in Aspergillus and other Plectomycete fungi*

The Aspergilli are a group of fungi which include a series of industrially, medically and agronomically important species. This research examined mating type genes involved in the sexual reproduction in the Aspergilli. The researchers also identified 'sex-related' genes in species that are supposedly 'asexual', a result that may have significance for disease control of pathogenic Aspergilli or for strain improvement for biotechnology and industry. The work resulted in a large number of publications in high impact journals that included 'Current Biology' and 'Nature'.

*Shape and form in microbial cells: the structural basis for cell division in trypanosomes*

Trypanosomes are small single celled parasitic protozoa, that can cause a variety of diseases, including the fatal sleeping sickness in humans. When a trypanosome divides, two daughter cells of a similar shape are produced upon division. This research discovered the structural information in the old cell is used to modulate the shape and form of the new cell, supported by the evidence from flagellum-cytoskeletal structure analysis. This research also presented genetic analysis on the FAZ gene, a strain-specific essential gene involved in flagellum production and cell division. The work was published in high ranking journals, including 'Science'. The group also actively brought the work to the public by presentations in several schools.

*Signal transduction, microtubule dynamics and calcium signalling during vegetative hyphal fusion in Neurospora*

Although much is known about fusion between non-identical cells (e.g. sperm and egg cells), little is known about 'self-fusion' between genetically identical cells. This research used the fungus *Neurospora crassa* as a model to improve our understanding cell fusion in animals, plants and microbes. The research resulted in a large number of papers in high-ranking journals. In addition, the research has potential to provide a mechanism to generate genetic variation in species (particularly plant pathogens) that do not undergo sexual reproduction in nature.

*Studies into the role of aquaporins for regulating water supply to growing leaf cells and partitioning in mature tissues*

This project investigated the molecular processes affecting water movement between xylem and expanding leaf cells. The research studied the biochemistry of barley leaf membrane proteins involved in water transport during leaf growth. This grant established the PI in an academic position in the UK, and helped them to build a productive research programme. The project led to further funding from BBSRC and the Leverhulme Trust, as well as five papers in refereed journals.

*The function of histidine kinases during oxidative stress responses in Arabidopsis*

This research focused on isolating *Arabidopsis* histidine kinases that may act as hydrogen peroxide sensors. The work identified ETR1, a central component in response to the plant hormone ethylene, as a potential target for hydrogen peroxide perception and signalling. The researchers also showed that ethylene induces the production of peroxide in guard cells during stomatal closure. The results strongly improved our knowledge on integration of signals during important conditional or developmental processes in plants.

*The function of LuxS and its cognate autoinducer in bacterial central metabolism*

This research brought new knowledge on the physiological roles of LuxS, an enzyme involved in the synthesis of the autoinducer AI-2 (a bacterial signalling molecule). The group developed a novel technique which can assess the levels of the intracellular metabolites. The technique is amenable to high throughput usage and is likely to be widely used. The projects research outputs were excellent, achieving good publications during the project period as well as later on. The group also brought the work to the public by taking part in a BBC radio programme.

*The function of structural domains of pectic polysaccharides in growth and development*

Pectin is a plant polysaccharide, familiar for its gelling properties in food preparations. This project studied the spatial arrangement of pectins in *Arabidopsis* cell walls and searched for genes and proteins involved pectin synthesis and assembly. The project resulted in a US patent for a monoclonal antibody specific for homogalacturonan and a large number of peer-reviewed papers. The work was followed up with further funding from the BBSRC Agri-Food Committee.

*The programme underlying dormancy and autocrine resuscitation in Mycobacterium bovis BCG*

*Mycobacterium tuberculosis*, the causative organism of tuberculosis (TB) is able to persist in a quiescent manner in the body, but under certain conditions becomes active and causes clinical TB. The research from this Industrial Partnership Award employed a safer model organism – the BCG vaccine strain – to investigate the proteins involved in the end of the period of dormancy. The research produced a large number of publications in high-ranking journals. In addition, materials generated by this group have had led to potential targets for novel vaccines against TB.

*The role of soil physical conditions within the pathozone on fungal infection and biocontrol*

The spatial and temporal dynamics of microbes in the complex and competitive soil environment dictate the outcome of many ecologically and economically important processes. This research aimed to interpret the effects of soil physical conditions on the dynamics of fungal infection. The findings linked epidemiological concepts of fungal dynamics to soil structure and soil physical properties, with the observations and resulting models published in high impact journals. The research influenced subsequent developments in biophysical soil science and the role of organisms in structure formation.

*Trans-cellular Ca<sup>2+</sup> transport and Ca<sup>2+</sup> homeostasis in calcifying microalgae*

This research focussed on coccolithophores, marine phytoplankton that form a calcium carbonate shell and can form massive blooms in oceanic water. The research identified a novel chloride current involved in regulating membrane potential in *Coccolithus pelagicus*. This research was published in high-ranking journals given its environmental niche. The importance of the work was also shared with a wider audience at several public engagement events.

*Transcriptome analysis at the single cell level in embryonic cells of Arabidopsis*

The development of the basic body plan of a plant occurs during embryogenesis, within the seed. This research used laser-capture microdissection, in combination with DNA microarray analysis to identify genes expressed in specific regions of the *Arabidopsis* embryo. The transcriptomic data generated in the project were of use to both the academic scientific community and industry. The research resulted in an industrial CASE award, a UK patent application, and contributed to the formation of a spin-out company, 'Creative Gene Technology Ltd.' that is developing strategic targets for the agrochemical and food industries.

## Other notable grants

### *Biotrophy-related proteins specific to the intracellular hyphae of Colletotrichum lindemuthianum*

*Colletotrichum lindemuthianum* is a plant pathogen that causes anthracnose of common bean plants. This research studied a major glycoprotein that is found at the interface between fungal infection structures and infected bean epidermal cells. The work resulted in several publications in high ranking journals.

### *Characterization of biofilm development in Rhodobacter sphaeroides*

This research was based on the unique observation of significant morphological changes when the bacterium *Rhodobacter sphaeroides* forms a biofilm. Flagellum, chemotaxis and cell-cell communication have been shown to have a role in biofilm formation and structure. This project identified some novel genes specifically expressed within biofilms using recombinase-based *in vivo* expression technology.

### *Developing a functional flagellar toolkit by studying chimeric proteins*

This project investigated how the microscopic parts of natural-rotary propeller engines from bacteria, called flagellar motors, interact to make them work. The research produced good publications in high-ranking journals. The researchers also made a concerted effort made to bring their work to a wider public audience.

### *Functional characterization of mutants of the PufX protein from Rhodobacter sphaeroides*

Puf X is a protein responsible for the proper assembly of the reaction centre/light harvesting complex 1 photosystem in *Rhodobacter sphaeroides*. This research investigated the functional changes of the site-directed mutants of PufX, using a novel experimental system such as millisecond-timescale transient absorption spectroscopy and a TPP+ electrode to measure membrane potential.

### *Host plant selection by aphids*

Aphids penetrate plant tissues with their mouthparts, locate the phloem elements and imbibe phloem sap. This research provided a fundamental insight that the reproductive decisions of aphids are made before feeding, without reference to chemical cues or nutritional factors associated with the phloem sap. The research also resulted in a large number of publications.

### *Insecticidal Photorhabdus toxins as alternatives to Bt*

This New Investigator grant aimed to investigate the insecticidal activity of the Toxin complexes (Tc) from bacteria of *Photorhabdus luminescens*. The research enabled the functional expression of oral activity of Tc toxins by combining three genetic elements in *E. coli*. These toxins were shown to be capable of rearranging the actin cytoskeleton of both insect and mammalian cell lines. Outputs from this work included a US patent and a CASE partnership with Syngenta.

### *Mechanism of a nitric oxide sensor in Escherichia coli*

Nitric oxide is produced at high concentrations by specialised human cells known as macrophages to poison engulfed bacteria or tumour cells. This research discovered that nitric oxide interacts directly with a bacterial regulatory protein to activate expression of genes required for nitric oxide detoxification. The findings from this project were published in a range of high impact journals, including Nature.

### *Molecular characterisation of the genes and enzymes of the gentisate pathway for aromatic catabolism*

This research studied a pathway for the catabolism of naphthalene in *Ralstonia* bacteria at the biochemical and genetic levels. The work was published in good journals and has potential impacts on bioremediation.

### *Proteases as pathogenicity determinants of the cereal pathogen Stagonospora (Septoria) nodorum*

*Stagonospora nodorum* is one of the world's major fungal diseases of wheat. The research from this Industrial Partnership Award examined the role of proteases in the infection process, and had industrial support until the company partner disbanded its fungicide development operation within the UK. The science produced was good quality and published in good journals.

*The role of extracellular enzymes in xenobiotic metabolism and uptake in plants*

This project investigated enzymes produced by plants around their cell walls that interact with the synthetic man-made chemicals, such as herbicides. The research demonstrated that a range of esterases are produced in several crop species, and also identified an esterase with a key role in detoxification. This was a LINK project and results were made available to the industrial partner to assist their crop protection chemical discovery programme.

## Original peer-reviewed research articles published in prestigious journals

Journal Title	Completed	Current	Total
<b>Highest impact multi-disciplinary journals</b>			
Nature	3	1	4
Science	2	3	5
Total	5	4	9
Proportion of all original articles	1%	4%	2%

<b>High impact prestigious or multi-disciplinary journals</b>			
Chemical Biology	4	0	4
Current Biology	5	1	6
Development	0	1	1
EMBO Journal	3	1	4
Federation of American Societies for Experimental Biology Journal	1	0	1
Genes and Development	0	1	1
Genome Research	1	0	1
Genome Biology	1	0	1
Journal of American Chemical Society	1	1	2
Journal of Biological Chemistry	30	4	34
Molecular Biology of the Cell	1	0	1
Molecular Cell	1	0	1
Nanoletters	1	0	1
Nature Biotechnology	1	0	1
Nature Cell Biology	0	3	3
Nature Genetics	0	1	1
Nucleic Acids Research	2	1	3
PLOS Biology	0	1	1
PLOS ONE	0	1	1
Proceedings of the National Academy of Science of the United States of America	8	6	14
Total	60	22	82
Proportion of all original articles	14%	20%	16%

<b>Prestigious journals in the field of plant and microbial sciences</b>				
Plant Sciences	Journal of Chemical Ecology	1	0	1
	New Phytologist	11	3	14
	Plant Cell	12	12	24
	Plant Cell and Environment	4	1	5
	Plant Journal	32	7	39
	Plant Physiology	17	7	24
Plant-Microbe Interactions	Molecular Plant Pathology	4	0	4
	Molecular Plant-Microbe Interactions	7	2	9
	Plant Pathology	2	0	2
Agronomy	Theoretical and Applied Genetics	1	0	1
Soil Science	Soil Biology and Biochemistry	1	0	1
Microbiology	Applied and Environmental Microbiology	7	1	8
	Cellular Microbiology	1	2	3
	Environmental Microbiology	1	0	1
	FEMS Microbiology Ecology	1	0	1
	Journal of Bacteriology	17	9	26
	Microbiology	13	6	19
	Molecular Microbiology	17	2	19
Virology	Journal of Virology	7	0	7
Mycology	Fungal Genetics and Biology	4	4	8
Total		160	56	216
Proportion of all original articles		38%	51%	41%

<b>Overall</b>				
Total (All articles reported)		225 (416)	82 (110)	307 (526)
Proportion of all original articles		54%	75%	58%