# Evaluation of BBSRC ‘genomics’ research

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This document represents the views and conclusions of a panel of experts

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# Contents

# Abbreviations

| | |
|---|---|
| BBSRC | Biotechnology and Biological Sciences Research Council |
| BIS | Department for Business, Innovation and Skills |
| CASE | Collaborative Awards in Science and Engineering |
| COGEME | Consortium for the Functional Genomics of Microbial Eukaryotes |
| Defra | Department for Environment, Food and Rural Affairs |
| DfID | Department for International Development |
| EPSRC | Engineering and Physical Sciences Research Council |
| EU | European Union |
| GARNet | Genomic *Arabidopsis* Resource Network |
| HEFCE | Higher Education Funding Council for England |
| IF | Impact Factor |
| IGF | Investigating Gene Function (initiative) |
| IP | Intellectual Property |
| IPA | Industrial Partnership Award |
| NERC | Natural Environment Research Council |
| MRC | Medical Research Council |
| NIH | National Institutes of Health |
| RA | Research Assistant |
| UK-BRC | UK Brassica Research Community |

# Introduction

# 1. Introduction

This document sets out the views of a specialist Review Panel convened to provide an independent evaluation of two programmes of BBSRC-supported 'genomics' research:

- **The Investigating Gene Function (IGF) initiative**: funding for consortia to develop access to high-throughput 'genomics' technologies and associated resources for communities working on organisms key to the BBSRC remit

- **'Genomics' research funded through responsive mode**: investigator-driven research from across the BBSRC remit which incorporates 'genomics' technologies and approaches

The Panel's conclusions and recommendations regarding these two areas of funding were reached separately, although consideration was given to how they complemented one another. The findings are presented in separate sections of this report (beginning on pages 11 and 39, respectively).

## 1.1 Introduction to BBSRC

1. The Biotechnology and Biological Sciences Research Council (BBSRC) 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 exchange 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-supported 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 targeted to fund grants that will deliver specific strategic objectives.

3. 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.

## 1.2 Evaluation context

4. BBSRC is committed to the effective evaluation of the research and training it funds, as part of its strategy for evidence-based decision making. Evaluation plays a central role in:
   - enabling BBSRC to account to government, the public, the scientific community and other stakeholders for the funds it allocates
   - justifying BSBRC 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
   - helping BBSRC to improve its policy and practice, through informal policy decisions and the design of new schemes, programmes and processes; and through identifying good practice, lessons learned and ways to improve processes

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

| | |
|---|---|
| Project: | • evaluation of final reports from grants |
| Scheme: | • evaluation of major research investments, for example, through responsive mode or research initiatives (time-limited research funding in strategically significant areas)<br>• evaluation of funding schemes (e.g. international Partnering Awards, Research Industry Clubs, fellowship schemes) |
| Institution: | • Institute Assessment conducted every five years at the BBSRC-supported Research Institutes |

6. BBSRC's Evaluation Framework[1] outlines the Council's approach to evaluation and the methodology used.

## 1.3 Definition of 'genomics'

7. For the purposes of this evaluation, 'genomics' is used as a collective term to describe a variety of 'omics' technologies and approaches:
   - transcriptomics
   - proteomics
   - metabolomics
   - functional genomics
   - large scale sequencing projects

8. This definition includes research with a number of different objectives:
   - research which is developing 'omics' resources for the wider community
   - research which is addressing specific biological questions using 'omics' technologies and approaches (either as the primary focus of the grant or more peripherally)
   - research which would not be classified as 'omics', but which may underpin future developments in 'omics'

[1] www.bbsrc.ac.uk/researchevaluation

## 1.4 Evaluation methodology

9. The aim of the evaluation was to obtain an independent scientific assessment of BBSRC 'genomics' research supported through the IGF initiative and responsive mode. Specifically, the objectives were to:
    - assess the quality and international standing of the research
    - identify the major outputs and outcomes of the research
    - assess the balance and coverage of the 'genomics' research portfolio
    - assess the economic and societal impacts of the research
    - assess the extent to which the original objectives of the IGF initiative were met
    - determine whether IGF initiative funding through consortia provided any benefits that could not have been realised through more standard funding mechanisms
    - assess the extent to which the IGF initiative enabled the wider research community to incorporate 'genomics' approaches and technologies into their research programmes
    - identify ways to build on successes and address identified gaps and issues.

10. Information was gathered from a number of sources:

    - **IGF initiative grantholders**: A questionnaire was sent to all Principal Investigators who were awarded funding through the IGF initiative. The survey covered topics including the success of the grant, research outputs and outcomes, economic and societal impacts, and views on the objectives, scope and management of the initiative.
    - **Responsive mode grantholders**: A questionnaire was sent to a structured sample of 110 researchers who were awarded a 'genomics' grant between 1999 and 2005[2]. The survey covered topics including the success of the grant, research outputs and outcomes, economic and societal impacts, and views on BBSRC's support for 'genomics' research.
    - **BBSRC data**: Relevant data were collated including the final reports submitted by grantholders, and information from the BBSRC grants database.

11. The questionnaires are reproduced at Appendix 2. The survey responses were received between July and October 2009.

12. The evidence collected for the evaluation was reviewed by a Panel of independent experts who are not significantly involved with BBSRC, but who are nevertheless familiar with the research in this area, and who between them have expertise across the BBSRC remit. The Panel included industry and international representatives.

13. The sample of responsive mode grants was selected because the research was using or developing 'genomics' technologies and approaches. It should be noted that the use of 'genomics' may not have been the primary focus of the research. The outputs and outcomes reported in this document relate to the research projects as a whole; they are not necessarily direct outputs and outcomes of the 'genomics' aspects of the research.

[2] One additional grant was included in this sample, but is excluded from the analysis in the report. This grant aimed to facilitate UK efforts in structural genomics by providing a synchrotron X-ray source for macromolecular crystallography. The grant was very successful: a high-quality beamline was commissioned and built in a short space of time; the research outputs from the beamline were very good; and the beamline was very much appreciated by the UK research community. The grant delivered the best protein crystallisation beamline in the UK at the time. However, subsequent funding to develop a structural genomics protein pipeline was not obtained and, therefore, the Panel agreed that the grant should not be included in the evaluation.

14. It should be noted that this evaluation does not address all BBSRC's 'genomics' initiatives. BBSRC supported three other initiatives and programmes over the evaluation period: 'Exploiting Genomics', 'Applied Genomics LINK' and 'Proteomics and Cell Function'.

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# The Investigating Gene Function initiative

# Executive Summary: The Investigating Gene Function initiative

This section reports the findings of an independent evaluation of the Investigating Gene Function (IGF) initiative. The objectives of the evaluation were to assess the quality of the research supported and to identify the major outcomes arising from it; to assess the extent to which the original objectives of the initiative were met; to consider whether the funding of the initiative through consortia was beneficial; to consider the balance and coverage of the portfolio; to assess the extent to which the initiative enabled the wider research community to incorporate 'genomics' approaches into their own research programmes; and to identify ways to build on successes and address identified gaps and issues.

The Panel's analysis was based on all 21 final reports from the 22 initiative grants, as well as questionnaire responses which updated the final reports of 17 of these grants.

# Key Conclusions

## 1. The IGF initiative was a very successful programme which delivered essential underpinning resources for key areas of research within the BBSRC remit

The initiative met its objectives of providing increased access to 'genomics' tools and technologies, and increasing focus and coordination within specific research communities. It provided enabling tools, resources, facilities and datasets, which were accessed by UK and international researchers. The initiative had a substantial impact for a relatively modest investment and delivered good value for money for BBSRC. It helped to embed 'genomics' into UK biological research and underpinned future research across the BBSRC remit.

## 2. The overall quality of the outputs arising from the initiative was very high

The key outputs produced by the initiative were 'genomics' tools, resources, facilities and datasets. The outputs were relevant to large sections of the BBSRC research community and were state of the art at the time. This was ensured, in part, by grantholders actively responding to the rapid advances in 'genomics' technology and adapting their research programmes accordingly. The establishment of ten new Centres which provided facilities for other research groups was a particularly notable achievement; many of these Centres are still operating, having made the transition to cost recovery. The success of the initiative was also evident in the quality and number of other outputs, including publications in peer-reviewed journals, further funding to develop the research, and the establishment of new academic partnership links. A relatively low proportion of researchers applied to secure intellectual property rights as a result of their grant, but this was appropriate as the objective of the initiative was the development of freely available resources and services for the wider community.

## 3. The initiative played a very important role in capacity building and provided good training and skills development

The initiative provided an important training platform for a good number of postdoctoral researchers and technicians. Several postdoctoral researchers secured permanent academic posts as a result of their participation in the initiative, and a small number moved into industry. However, there was no formal objective to provide postgraduate student training within the initiative, and this was a notable weakness. Greater support for postgraduate training may have helped address some of the substantial difficulties experienced by responsive mode grantholders when seeking to recruit staff with 'genomics' skills.

## 4. The initiative developed public resources and encouraged data sharing

The initiative met its objective of providing accessible 'genomics' resources to the research community. It helped to foster a culture of openness and data sharing among UK bioscience researchers, and it succeeded in placing high-throughput 'genomics' data into the public domain. It also contributed to the standardisation of methodologies and protocols, improving quality assurance and enabling data comparisons between research groups. However, insufficient emphasis was given to the long-term maintenance and curation of the resources and datasets developed by the initiative.

## 5. An increased level of networking and collaboration was an important outcome of the initiative

Grantholders within individual consortia developed very strong collaborative partnership links with one another as a result of the initiative, many of which are still in place. In addition, the initiative promoted networking and collaboration within the wider research community, helping nascent research communities establish themselves and strengthening existing communities. This was an important outcome of the initiative and it had a lasting impact. The majority of networking and collaboration promoted by the initiative was between academic researchers. There was potential for a greater degree of interaction and knowledge exchange with industry within the initiative, and it was a little disappointing that opportunities for such interactions had not been fully explored.

## 6. The balance and coverage of the portfolio was appropriate

The initiative focused on key groups of animal, plant and microbial species within the BBSRC remit. It was appropriate to concentrate the available financial resources on a limited group of organisms and, even with this focused approach, the investment in individual consortia was relatively modest. The balance and coverage of the portfolio was also appropriate in the context of other support for UK 'genomics' research available from other funding bodies at the time. Broader coverage of the BBSRC remit was delivered through responsive mode funding.

## 7. The consortia funding mechanism was an effective way of providing community resources and establishing the use of new technologies

The organisation of the IGF projects within seven consortia contributed to the success of the initiative. It helped to raise the overall quality of research and ensured that the funds were used effectively. The consortia funding mechanism ensured that research activities were coordinated and that research teams could react quickly to alternative approaches and discoveries by other members of the consortium. It is unlikely that the initiative's high number of outputs and outcomes would have been delivered by a similar investment in responsive mode funding.

## 8. Steering Committees made a valuable contribution to the initiative

Each consortium had its own Steering Committee and these also contributed to the initiative's success. The Steering Committees helped to coordinate and prioritise research activities, they promoted interactions between grantholders, and they provided support for smaller, less established teams. They also provided guidance on interactions with the wider research community, and helped to prioritise access to facilities and resources in an open and fair manner. Overall, the Steering Committees were viewed as effective and beneficial by grantholders. However, it may have been useful to have joint meetings between the Steering Committees and the IGF Board to consider generic issues within the initiative as a whole.

## 9. The initiative has underpinned research from across the BBSRC remit which is likely to deliver economic and societal impacts in future

The initiative contributed to the substantial momentum in UK 'genomics' research at the time, and it enabled large sections of the BBSRC research community to incorporate 'genomics' technologies and approaches into their research programmes. The initiative was intended to be fundamental and underpinning, focused on the delivery of tools, resources, facilities and datasets for the wider community. As such, its main impacts were achieved through skilling the community rather than directly leading to economic benefits. The major economic and societal impacts will be delivered by other research activities which were underpinned by the initiative. It is likely that the investment in the initiative compressed the amount of time between the introduction of new 'genomics' technologies and their eventual delivery of impacts.

## 10. The initiative helped to maintain the international competiveness of UK bioscience research

The investment in 'genomics' enabled UK researchers to conduct high-quality research and it raised the profile of UK bioscience research. It enabled the UK to contribute to a wider set of 'genomics' tools and resources being developed by other countries, such as the USA and the rest of the European Union, and it positioned UK bioscience researchers so that they were able to contribute to and influence the development of

other multi-national ‘genomics’ research programmes. Overall, the initiative made a valuable contribution to the international standing of UK bioscience research.

## 11. The initiative was timely and delivered long-lasting benefits to the UK bioscience community

The IGF initiative was established at an early stage in ‘genomics’ research in the UK, with the intention of stimulating and underpinning further research using ‘genomics’ technologies. It developed a collection of ‘genomics’ resources which were relevant to BBSRC research communities. ‘Genomics’ technologies have developed rapidly since the initiative’s inception and, as expected, some of the tools and resources have subsequently been superseded. However, many of the initiative’s broader outcomes have proven to be long-lasting and their benefits are still evident. A cohort of scientists was trained in ‘genomics’ research, capacity in ‘genomics’ research was increased, and research communities were strengthened. The initiative contributed to the maintenance of a strong, internationally-competitive UK research base, which is able to address emerging global challenges. The initiative underpinned research from across the BBSRC remit which is delivering benefits to the UK, using ‘genomics’ approaches to address areas such as food security, human health, industrial biotechnology, animal health and welfare, the environment and the development of government policy. Overall, the initiative was an excellent investment of BBSRC resources.

# 2. Introduction to the Investigating Gene Function initiative

## 2.1 The Investigating Gene Function initiative

15. In 1998, the government's Comprehensive Spending Review identified a need for the UK to invest in 'genomics' research and support was provided for cross-Council programmes in Genomics and Post-Genomics. The Investigating Gene Function (IGF) initiative was launched in 1999 as part of BBSRC's contribution to these cross-Council funding programmes. The initiative's aim was provide access to functional genomics technology and resources for key BBSRC research communities.

16. The initiative provided support for seven consortia which focused on major model organisms and species representative of key groups of organisms of economic significance. These were animal species (farm animals, *Drosophila*), plant species (*Arabidopsis*, brassicas, cereals), and microbial species (*Streptomyces*, yeast and fungal pathogens). The total value of awards was £20.2M.

**IGF initiative spend by consortia**

| General area | IGF initiative consortium[1] | Value (£M) |
|---|---|---|
| Animals | ARK-genomics (Farm animals) | 4.3 |
| | *Drosophila* | 3.5 |
| Plants | GARNet (*Arabidopsis*) | 4.1 |
| | *Brassica* | 1.6 |
| | Cereals | 2.1 |
| Microbes | COGEME (Microbial eukaryotes) | 3.3 |
| | *Streptomyces* | 1.2 |

[1] Abbreviations: COGEME: Consortium for the Functional Genomics of Microbial Eukaryotes; GARNet: Genomic *Arabidopsis* Resource Network

17. The initiative was the second phase in BBSRC's programme to support genomics research, following the 'Functional Genomics Toolkit' initiative. It was anticipated that the IGF initiative would be followed by further initiative and standard responsive mode activities in gene function studies focused on particular biological questions in animals, microbes or plants.

## 2.2 Objectives of the initiative

18. The objectives of the IGF initiative were to:

    - make available methods and resources whereby the connection between genes and important functions can be discovered using genomics, through providing access to, for example, microarrays, filter arrays and proteomics
    - support the creation of new mutant libraries and similar essential resources, specialised screening of new and existing libraries, and distribution of mutant collections
    - increase focus and coordination in the community by supporting collaborative and systematic approaches to function search and gene identification within consortia based on model organisms or key organisms of commercial significance which are central to the BBSRC mission

19. The expected outputs of the IGF investment were:

    - increased knowledge of genes and their functions in model organisms and key organisms of commercial significance
    - increased access to high-throughput technologies (e.g. microarrays and scanners) and associated proteomics, based around, for example, central provision within a research institution (or via industrial contract in the case of high-density work), a distribution network and separate 'readers' at distributed sites
    - increased focus and coordination within the community, based on systematic, consortium-based approaches to function search and gene identification targeted on model and key organisms
    - an enhanced archive of materials and data accessible to the broadest possible UK community
    - enhanced output of trained postdoctoral researchers and technicians underpinning functional genomics research

## 2.3 Management of the IGF initiative

20. Each of the seven consortia had a Steering Committee comprising representatives of the project team, the user communities and BBSRC nominees. Each Steering Committee produced six-monthly reports to the IGF Board.

21. The IGF Board maintained an overview of progress within the initiative. The Board was comprised of a number of scientifically-influential individuals drawn from BBSRC Council, Strategy Board and programme representatives. It had an ongoing monitoring role, formally at the annual grantholder Forum meetings, and less formally through visits to grantholders. It also provided the focus for networking and coordination activities for the initiative and associated consortium Steering Committees, and reported to BBSRC Council.

# 3. IGF initiative: Standard of research

## Summary

- The general standard of research supported by the IGF initiative was very high
- The key outputs of the initiative were enabling 'genomics' tools, resources, facilities and datasets for the wider research community
- The tools and resources were relevant and state of the art at the time of the initiative, although many have subsequently been superseded
- The establishment of the IGF Centres, which provided access to 'genomics' technologies, was particularly notable
- There was insufficient emphasis on the long-term maintenance of resources and curation of datasets developed during the initiative
- Several grants experienced staffing difficulties which delayed progress

## 3.1 Context of the evaluation

22. The IGF initiative ran between 2000 and 2005. This was a relatively early period in 'genomics' research when the associated techniques and methodologies had not yet been routinely established for many organisms. The IGF initiative provided support to develop 'genomics' tools and resources for a number of key animal, plant and microbial species within the BBSRC remit. It should be noted that, at the outset of the initiative, the availability of genome sequence information for each of the supported species differed considerably, and the related 'genomics' technologies were at different stages of development. This influenced the objectives and activities of individual consortia and must be taken into consideration when assessing the outputs and outcomes of each consortium.

23. IGF grantholders had a range of previous experience with 'genomics' technologies and approaches. 63% had previously received funding for 'genomics' research, supported by a range of funders including the Agricultural and Food Research Council (AFRC), BBSRC, Department for Environment, Food and Rural Affairs (Defra), Department of Trade and Industry (DTI), the European Union (EU), the Gatsby Charitable Foundation, and industry. 37% had not previously received funding for 'genomics' research and the initiative represented their first opportunity to develop 'genomics' expertise.

## 3.2 Research quality

24. The research within the IGF initiative was generally of an excellent standard. The majority of projects were of an international quality and had met or exceeded their original objectives. At the time of the initiative, the supported research groups were world-leading in 'genomics' research.

25. The very high standard of the research within the portfolio is demonstrated by the final report grades of the grants. All Principal Investigators funded by BBSRC are required to submit a final report within three months of the completion of their grant. These reports

are assessed and graded by the appropriate BBSRC Research Committee on a scale of A to D[3], taking into account the quality of the research undertaken and the extent to which the original objectives of the project were met. An analysis of the grades awarded to the 21 IGF grants for which there were final reports shows that all were graded either 'A' or 'B' (A: 38%; B: 62%). This compares very well with the general distribution of grades in the wider responsive mode portfolio, where approximately 80% of grants are awarded 'A' or 'B' grades.

## 3.3 Research outputs

26. Overall, the quality and quantity of outputs arising from the initiative were very good. The principal outputs were tools, resources, facilities and datasets for 'genomics' research. A particular highlight was the establishment of the IGF Centres which provided the wider research community with access to 'genomics' technologies. The other outputs of the initiative were also of a high standard, and included publications in peer-reviewed journals, further funding to develop the research, and the establishment of new academic partnership links.

27. The outputs reported in this section are collated outputs from the whole IGF initiative incorporating, where appropriate, data reported by consortium. It should be noted that these data are a likely to be a considerable underestimate of the total outputs of the initiative, as they do not include outputs from other researchers who used the IGF tools, resources, facilities and datasets. Information on user outputs was not captured in the majority of IGF grantholder final reports; this was a weakness which limits the assessment of the wider impacts of the initiative.

## 3.4 New tools and resources for 'genomics' research

28. The development of new tools and resources for 'genomics' research was a major achievement of the initiative, as was the large number of enabling resources made available to the wider community. It was especially notable that the development of these resources was community-led, which ensured that they addressed user needs. The outputs included physical resources (e.g. clones, libraries, microarrays, mutant lines) and other tools, data and knowledge (e.g. methodologies, protocols, sequence information, software).

29. The most significant tools and resources developed by individual consortia are summarised in on page 21. The specific outputs from each consortium were varied, but were appropriate to the state of 'genomics' technology development and the availability of genome data for the corresponding organisms. They were made available through IGF Centres, stock centres and websites. In most cases the users were members of the UK academic community. Other users included industry and international academics.

[3] 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 added significantly 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.

Researchers in the ARK-genomics consortium developed a comprehensive collection of tools and resources for functional genomics and genome research in farm animal species. A particular highlight was the development of nine different microarrays for expression profiling in chickens, pigs and cattle. These microarrays were used in a number of collaborative research projects to study changes in gene expression in response to a variety of challenges, with an emphasis on immune systems and infectious diseases.

Researchers in the *Streptomyces* IGF consortium developed a procedure that dramatically increased the ease of genetically manipulating streptomycete bacteria. They established a PCR-based technique for targeted gene disruption, and used this to investigate the function of genes and gene sets involved in the production of antibiotics and other important secondary metabolites.

Grantholders working within the COGEME consortium developed the first microarrays for several fungal plant pathogens. These included *Mycosphaerella graminicola* (a disease affecting wheat) and *Blumeria graminis* (which causes powdery mildew in grasses such as wheat, barley, oats and rye). Research using these microarrays will contribute to understanding and combating plant disease, thereby improving food security.

Researchers in the GARNet and *Drosophila* consortia developed robust methodologies for proteomic investigations. They validated and improved proteomics technologies so that they met the needs of the *Arabidopsis* and *Drosophila* research communities. An important aspect of this work was the standardisation of data capturing and archiving.

'Genomics' research in Brassica was at an early stage of development at the time of the initiative compared with other species. The *Brassica* consortium developed physical maps of the *Brassica* A and C genomes, which was the first step towards the provision of resources and services to accelerate the identification of gene function. The bioinformatics tools developed through the initiative were particularly important in bringing together all aspects of the consortium's research programme.

The Cereals consortium developed valuable genomic libraries for use in cereals research. They produced a high quality BAC library to the Chinese Spring variety of wheat, which consisted of 1.2 million clones: 700,000 were generated by the consortium and a further 500,000 were contributed by collaborators in France. A 30,000 clone BAC library was also made to the wild grass *Brachypodium sylvaticum*, a model organism for grass research which has a small genome.

30. The tools and resources developed through the initiative were state of the art and relevant to BBSRC research communities. Since the end of the initiative, some have been superseded by new technologies, as might be expected since 'genomics' technology has advanced rapidly. Nevertheless, the tools and resources were very useful to the UK bioscience community at the time.

31. The development of standardised protocols and methodologies was also valuable. The initiative contributed to the adoption of international data standards within the UK bioscience community, which helped to improve quality assurance and enabled data comparisons between research groups.

32. The arrangements for the long-term maintenance of the tools and resources developed through the initiative were a matter of some concern. Insufficient emphasis was placed

on this at the outset, and subsequently a few of the resources developed have been lost. In future funding programmes, BBSRC should consider the long-term maintenance of resources more carefully, particularly how such activities will be funded.

**Key 'genomics' tools and resources developed through the IGF initiative**

### ARK-Genomics (farm animals)

- repository of over 1.5 million cDNA clones from cattle, chickens, pigs, salmon and sheep
- repository of BAC clone libraries for cattle, chickens and pigs
- EST sequences from cattle, chickens and pigs
- nine microarrays for expression profiling in cattle, chickens, pigs, salmon and sheep
- database and website resources

### *Brassica*

- contiguous physical maps for *Brassica rapa* (A) and *Brassica oleracea* (C) genomes
- integration between *Brassica* genetic and physical maps, functional loci, and the *Arabidopsis* genome
- bioinformatics software
- database and website resources

### Cereals

- hexaploid wheat BAC library (700,000 clones)
- *Brachypodium sylvaticum* BAC library (30,000 clones)
- resources for wheat and barley transcriptomics: cDNA libraries, EST sequences, microarrays
- a high density gene knockout array representing 10,000 maize lines with active *Mu* elements
- database and website resources

### COGEME (Microbial eukaryotes)

- transcriptomics resources for yeast and fungi, including the first microarrays for *Mycosphaerella graminicola*, *Blumeria graminis* and *Aspergillus nidulans*
- proteomic resources and methodologies
- bioinformatics tools and resources
- database and website resources

### *Drosophila*

- the DrosDel collection: a genetic resource which facilitates designer genome manipulations
- microarray platforms for transcriptomics
- methodological advances in proteomics
- database resources for capturing, querying and disseminating genomics data

### GARNet (*Arabidopsis)*

- microarray platform for transcriptomics
- methodologies for proteomics
- methodologies for metabolomics
- new plant transformation competent genomics libraries with anchoring end-sequences
- a collection of high copy number transposon lines for forward genetics
- a collection of sequenced insertion sites for transposon lines for reverse genetics
- a collection of genomic sequence tags suitable for microarray construction
- bioinformatics, database and website resources

### *Streptomyces*

- methodology for PCR-based targeted gene disruptions
- a recombinase based system for generating targeted deletions
- *in vitro* transposon mutagenesis
- novel vectors and promoters to manipulate gene expression
- novel integrase for genome engineering
- database and website resources

## 3.5 Centres and facilities

33. One of the anticipated outputs of the IGF initiative was the establishment of centralised facilities to provide improved access to 'genomics' technologies. The IGF initiative was very successful in delivering these facilities, and ten new Centres were established. These were important developments, as there was limited 'genomics' infrastructure available to the BBSRC research community prior to the IGF initiative. Initially, they provided access to 'genomics' technologies at no or reduced cost, and they were used by both UK and international academics.

34. Seven of the Centres are still operating. The majority have made the transition to cost recovery, illustrating that they are used and valued by the research communities they serve. They have adapted since the initiative ended, altering the scale of their activity, expanding into new areas, and adopting new technologies. Details of the individual centres are provided below.

**UK Centre for Functional Genomics in Farm Animals**: the Centre was set up at the Roslin Institute by the ARK-genomics consortium in 2001 and is still operating today with seven members of staff. It has provided leadership to create a farm animal genomics community, in particular supporting researchers working with avian, porcine and ruminant genomes. It has been involved in the exploitation of genome resources from chicken, pig and cattle by providing access to clones, chips, and genotyping tools world-wide. It has also provided tools and training to the research community, both in-house and through national and international collaborations. The Centre has moved from a focus on gene expression studies to a full genomics facility. It provides user access to modern technologies for DNA- and RNA-based experiments, including DNA sequencing (next generation Illumina), RNA sequencing (Illumina), gene expression chips, ChIP-sequencing and high throughput genotyping, as well as bioinformatics support. Long-term sustainability is through a combination of cost recovery, grant and institute funding.

**DrosDel Collection**: the DrosDel Collection of functional genomics resources was established at the University of Cambridge in 2000 by the *Drosophila* consortium and had two members of staff. It has also received funding from the Wellcome Trust. Its key achievements include the DrosDel P-element insertion collection, the DrosDel 2nd generation deletion kit, and the Cambridge Protein Trap collection. It was still operating in 2009, but is unlikely to continue beyond 2010 due to developments in fly genetic manipulation. However, all stocks will remain available for access.

**FlyChip Microarray Facility**: this transcriptomics facility was established in 2000 by the *Drosophila* consortium at the University of Cambridge with three members of staff, and was still operating in 2009. Funding has also been received from MRC and the Foundation for the National Institutes of Health. Its major achievements include: the provision of access to array technologies for researchers in the UK fly community, the development of *in vivo* ChIP-array technologies, and contributions to the International Drosophila Array Consortium. The facility is now within the Cambridge Systems Biology Centre and supplies fly genomics resources on a cost recovery basis.

**InterMine Database Group**: this bioinformatics group was set up by the *Drosophila* consortium at the University of Cambridge in 2004 with eight members of staff and grew out of the computational infrastructure supporting the IGF initiative. It was still operating in 2009 and has also received funding from the Wellcome Trust and NIH. The team has developed novel solutions for data warehousing and integration and its key achievements include the FlyMine integrated database, the InterMine generic data warehouse infrastructure, and the modMINE, integrated infrastructure underpinning the modENCODE project. It relies entirely on grant funding.

**Cambridge Centre for Proteomics (CCP)**: the CCP was established at the University of Cambridge in 2000 as a joint activity between two IGF consortia (GARNet and *Drosophila*). It was still operating in 2009 with 14 staff. It has received additional funding from the Wellcome Trust, EU, MRC and HEFCE. It acts as a mass spectrometry centre of expertise, and its major achievements include the development of robust quantitative and comparative proteomics methods, and the development of high-throughput metazoan affinity purification methods. Long-term plans include operating as a self-funding core facility, and as a proteomics research laboratory, directed by staff originally employed on IGF initiative grants.

**NASC *Arabidopsis* Array Service**: This facility was set up at the University of Nottingham by the GARNet consortium. The Array service was set up in 2000 followed by a GeneChip service in 2002. It was still operating in 2009 with 1.5 staff. Its wet-work is full cost recovery, although BBSRC funds the associated informatics and dissemination work. Its main achievements include over 6,000 GeneChips being put into the public domain, providing the cheapest public UK GeneChip service for academics, and open access data and tools for array analysis. Its long-term objectives are to continue expanding into new animal, plant and fungi species, to support new GeneChip platforms, and to expand into a similar open data service for other plants (tobacco, *Brassica*, *Brachypodium*).

**Metabolomics at Rothamsted (MeT-RO)**: the Centre was established in 2003 at Rothamsted Research by the GARNet consortium and was still operating in 2009 with four staff. It carries out plant and microbial metabolomic screening, and has generated additional service income from industry, overseas academics and other research grants (EPSRC and EU). Its key achievement is the ability to provide a complete multi-level metabolite analysis service from plant growth through analytical data collection (25,000 data sets/year) to extensive data analysis, using in-house developed software tools and metabolite libraries. Long-term plans include continuing with high-throughput plant metabolomic screening research whilst contributing key input into collaborative biological/genetic investigations, including large scale genome-wide investigations using mutant and cultivar collections, Quantitative Trait Loci, Gene-Environment studies and the dynamics of plant metabolism in response to environmental change, biotic and abiotic stress. The financial model of raising income through collaborative grants and direct fee-for-service provision will be continued.

**Proteomics Research Facilities**: Two complementary proteomics research facilities were set up as part of the COGEME consortium, one based at the University of Aberdeen and the other at the University of Manchester. The Aberdeen facility focused on classical 2D-gel based proteomics and MALDI-ToF mass spectrometry to identify proteins whose levels change under particular conditions. The Manchester facility specialised in the development of new advanced mass spectrometry techniques to aid sample identification and increase sensitivity. The facilities performed service projects for users in the UK and international mycology communities. The Aberdeen facility is still operating as Aberdeen Proteomics.

**Transcriptomics Research Facility**: The COGEME consortium established a transcriptome research facility based at the University of Manchester. It produced arrays for several yeast and fungal species including *Saccharomyces cerevisiae*, *Mycosphaerella gramincola*, *Blumeria graminis* and *Aspergillus nidulans.* The facility was equipped to handle all commercial array platforms and extensive work was conducted to develop an optimise protocols for transcriptome experiments.

**Bioinformatics Centre**: This COGEME facility was based on two sites: the University of Manchester and the University of Exeter. The objective of the Manchester facility was to support the capture and analysis of transcriptome and proteome data from the experimental facilities. The objective of the facility at Exeter was to support the plant pathogenic fungi community through the management, analysis and dissemination of EST datasets. The project employed three members of staff, two at Manchester and one at Exeter.

35. Although the Centres were very successful, the practical aspects of operating a service under the constraints of a grant caused problems for some researchers. The financial management of some services proved very difficult, especially after projects moved into cost recovery. Providing a service also impacted on the career development of some research leaders, who were perceived more as technical experts than as innovative researchers.

## 3.6 Database submissions and data sharing

36. Electronic databases are an important way of disseminating research data to the wider research community. IGF grantholders recognised the importance of data sharing and they were enthusiastic about making their data widely available and accessible to other researchers. They made a large number of submissions to electronic databases which included research data (e.g. genome sequence information, transcriptomics, proteomics and metabolomics data) as well as information on the tools and resources developed through the initiative (e.g. functional genomics resources). Grantholders made their data available on their own websites, consortium websites and other public databases. The data were beneficial to the BBSRC research community as well as other UK and international researchers, and industry.

The NASC *Arabidopsis* array service, funded as part of the GARNet consortium, provided a very valuable transcriptomics service to the UK *Arabidopsis* research community. They established a pricing policy which was linked to the public availability of the data, which encouraged data dissemination and helped to foster an open research culture. At the end of the grant, the service had produced and released over 1500 sets of array data into the public domain.

37. The datasets provided by the initiative were a very valuable resource for the research community and they are still useful today. It is important that they remain accessible and are not lost. There were similar concerns regarding the long-term curation and archiving of datasets as there were for the maintenance of physical resources. BBSRC should ensure that data are properly curated and integrated into new databases as appropriate.

## 3.7 Publications

38. Data on publications were compiled from the 21 IGF grant final reports plus additional information for 17 grants for which questionnaire responses were received. It should be noted that publications were not expected to be the primary output of the funding. The initiative was focused on the development of 'genomics' tools and resources for the wider community, which does not necessarily lend itself to published outputs. Nevertheless, the number of publications arising from the initiative was good. In total, grantholders reported 219 publications in peer-reviewed journals, plus 28 other publications such as review articles, book chapters and articles in popular magazines. The number of papers published by consortium is shown below. These figures probably underestimate the total number of publications produced as a result of the IGF initiative as not all grantholders submitted a questionnaire to update their final report.

**Publications reported by each consortium**

| Consortium | Refereed papers | Other publications |
|---|---|---|
| ARK-Genomics | 19 | 2 |
| *Drosophila* | 37 | 9 |
| GARNet | 68 | 5 |
| *Brassica* | 4 | 1 |
| Cereals | 28 | 4 |
| COGEME | 46 | 3 |
| *Streptomyces* | 17 | 4 |
| **Total number** | **219** | **28** |

39. The publications included technical articles describing technological and methodological advances in 'genomics', research articles reporting the use of 'genomics' technologies to address specific biological questions and identify gene function, and general articles describing the tools, resources and facilities developed for specific research communities. The overall quality of publications was high. A good number of papers were published in high-impact journals or prestigious journals in specific fields; this was particularly so for research papers which were describing gene function.

Researchers in the *Drosophila* consortium published two papers in the journal *Genetics* describing functional genomics resources developed through the initiative. The papers described the first and second-generation 'DrosDel' toolkits for generating custom chromosomal aberrations in *Drosophila melanogaster*. The 'DrosDel' resources have had a considerable impact in the UK and international *Drosophila* community, and together the two publications have been cited over 140 times.

Researchers at the IGF-supported Cambridge Centre for Proteomics conducted research to describe the organelle proteome of *Arabidopsis thaliana*. The results were published in the prestigious journal *Proceedings of the National Academy of Sciences of the USA*. The paper has been cited over 160 times.

40. A large number of papers were also published in less prestigious journals, which is to be expected as the IGF projects were technology driven; papers describing technological and methodological advances are often published in journals with low impact factors. Although some of these papers were very technical and some were of poor quality, many were of value to the wider community.

41. As a result of the initiative, 65% of grantholders published a paper with an international co-author and 24% published a paper with an industrial co-author. This illustrates the highly collaborative nature of the research within the IGF initiative.

42. The IGF initiative contributed to a large number of other publications from users. Although few specific data were collected regarding these user outputs, it was clear that the other researchers had accessed the initiative's tools, resources, facilities and datasets, and this is likely to have resulted in many additional publications. For example, the ARK-genomics consortium reported an additional 64 refereed papers and the *Drosophila* consortium reported 50 additional papers (a large number of which were from users of the Cambridge Centre for Proteomics).

> Researchers at the University of Leicester collaborated with scientists at the Cambridge Centre for Proteomics and the Max-Planck-Institute for Plant Breeding Research to investigate the import of nuclear-encoded proteins into *Arabidopsis* chloroplasts. They characterised a mutant which was deficient in the accumulation of chloroplast proteins, and published their results in the prestigious plant science journal *Plant Cell*.
>
> Researchers at the Danish Institute of Agricultural Sciences used the transcriptomics resources developed by the Cereals consortium to investigate gene expression profiles during grain development of transgenic and wild-type wheat. They showed that the transgene had no significant effects on the overall gene expression patterns in the developing seed. The work was published in the specialist journal *Transgenic Research* and is an example of how genomics technologies can contribute to the safety assessment of transgenic plants.

43. Three IGF grants appeared not to have resulted in any publications, although for two of these grants no questionnaire response was received to update the final report.

## 3.8 New intellectual property and spin-out companies

44. As anticipated, relatively few intellectual property (IP) rights were developed as a result of the initiative. The aim was to develop resources for the research community which would be made freely available in a timely fashion; a requirement to protect IP would have been incompatible with this goal. Nevertheless, five grantholders applied for patents as a result of their grant. These patents were focused on methodological advances in functional genomics and transcriptomics.

45. The IGF initiative contributed to the establishment of two spin-out companies. One of these companies, Novacta Biosystems Ltd, is still trading.

The research supported through the *Streptomyces* consortium contributed to the establishment of the spin-out company Novacta Biosystems Ltd. The company is developing novel, naturally-derived products known as 'lantibiotics'. These products have anti-infective properties and may be useful in combating infections, such as those caused by *Clostridium difficile* (C-diff) and methicillin-resistant *Streptococcus aureus* (MRSA). The development of the company was supported by £4M in translational funding from the Wellcome Trust. In 2009, the company received a further £13.1M from investors.

## 3.9 Further funding

46. Grantholders were very successful in obtaining further funding to develop the work from the IGF initiative. 88% of grantholders received further funding, including support from BBSRC as well as other funding agencies. Obtaining research funding is very competitive, and grantholders' success in this area is another indicator of the high standard of the research conducted within the initiative.

47. Grantholders obtained 55 further grant awards from BBSRC, with a total value of almost £25M. In addition to this competitively-won funding, grantholders working at BBSRC-supported institutes received associated funding from institute strategic grants. Funding was also received from a wide range of external sources. These included the EU, European Regional Development Fund, Food Standards Agency, Horseracing Betting Levy Board, industry, Medical Research Council, National Institutes of Health (USA), Roslin Foundation, Scottish Enterprise Edinburgh and Lothians, and the Wellcome Trust.

## 3.10 Academic partnership links

48. IGF grantholders established a good number of academic partnership links with researchers from the UK and overseas, many of which were formal collaborations resulting in joint publications. The initiative also had a broader role in promoting networking and collaboration among the wider research community. Further details are provided in chapter 4, p. 33.

A grantholder in the COGEME consortium collaborated with colleagues in the USA and Germany. They published a paper in the prestigious journal *Nature* describing comparative assessment of large-scale data sets of protein-protein interactions. This paper has been cited over 930 times.

A researcher supported by the ARK-genomics consortium collaborated with other UK and international researchers in the development of resources for chicken genomics. They contributed to a paper describing a comprehensive collection of chicken cDNAs which was published in the high-impact journal *Current Biology*. This paper has been cited over 190 times.

## 3.11 The organisation and management of the initiative

49. The organisation of IGF projects within the seven consortia contributed to the success of the initiative and helped to raise the overall quality of research. It ensured that research activities were coordinated and that research teams could react quickly to alternative approaches and discoveries by other members of the consortium.

50. Each consortium had its own Steering Committee which also contributed to the initiative's success. The specific role of each Steering Committee varied, but in general they helped to coordinate and prioritise research activities, promoted interactions between grantholders, and provided support for the smaller, less established teams or those who encountered experimental difficulties. They also provided guidance on how to interact with the wider research community, and helped to prioritise access to the facilities in an open and fair manner. In addition, the Steering Groups made representations to BBSRC on behalf of grantholders, and put pressure on grantholders to succeed.

51. There was consensus among grantholders that the Steering Committees were effective and beneficial. However, it may also have been useful to have joint meetings between Steering Committees and the IGF Board to consider generic issues within the initiative as a whole, such as those associated with training, the provision of resources and facilities, and data sharing.

52. Other funding models could have been considered to organise the research and deliver the initiative's objectives. For example, the research could have been funded through responsive mode. However, this would not have provided the same level of coordination, focus or collaboration. In addition, grantholders were very doubtful that all the individual component grants, as well as the requests for staff and equipment infrastructure, would have been supported through standard responsive mode. Another alternative could have been to contract out the development of the 'genomics' tools and resources to industry. This may have provided the physical resources, but it would not have contributed to the development of 'genomics' infrastructure within academic institutions, or delivered the training and community building aspects of the initiative (the positive impacts of these other outcomes are still evident even though some of the physical resources have been superseded). Overall, the consortia funding mechanism was effective and provided good value for money. It is unlikely that the broad range of high quality outputs and outcomes would have been delivered through an alternative funding mechanism.

## 3.12 Issues affecting grant performance

53. Grantholders were very successful in meeting the original objectives of their individual grants, and in some cases they exceeded these objectives. However, some grantholders experienced issues which adversely affected their projects' performance, including staffing difficulties and experimental, technological or methodological difficulties.

54. Problems with the recruitment and retention of staff comprised the main issues affecting performance. Several grantholders had difficulties in recruiting staff with relevant technical skills. Others reported that staff left during the course of the grant, so they were forced to recruit and train new staff, delaying progress. For some projects, staffing difficulties were exacerbated by the routine and repetitive nature of the work required to develop the 'genomics' tools and resources. For example, some postdoctoral

researchers and technicians left the IGF projects after they were trained, to work on more exciting research projects based elsewhere within their institution.

55. The rapid pace of 'genomics' technology advancement also impacted on the initiative. Some of the tools and resources being developed became superseded by new technologies during the course of the grant (e.g. transcriptomics resources which became superseded by commercially available equivalents). When this occurred, grantholders acted appropriately, seeking to incorporate the technological innovations into the consortia's research programme. In a few cases, researchers sought and were awarded additional funding through responsive mode to include new technologies into their IGF programme.

> A researcher at the University of Glasgow was awarded a responsive mode grant to provide the UK *Drosophila* research community with access to Affymetrix GeneChips. The grant supported 54 projects using over 1000 microarrays, and complemented the powerful expression profiling technologies developed through the IGF initiative.

56. Some aspects of each consortium's research programme were less successful than others with, for example, some research objectives experiencing experimental difficulties. This may, however, have resulted from supporting adventurous and ambitious research, which needs to be supported despite the associated risks.

# 4. IGF initiative: Research outcomes and impacts

## Summary

- The initiative provided very good 'genomics' training for postdoctoral researchers and technicians, and helped to build capacity in UK 'genomics' research
- The initiative did not have a formal objective to provide training for postgraduate students, which was a weakness
- There was a relatively low level of interaction between grantholders and industry within the context of the initiative
- The initiative played an important role in strengthening nascent and established research communities within the BBSRC remit
- The initiative helped to embed 'genomics' into UK biological research
- The tools, resources, facilities and datasets developed through the initiative have underpinned future BBSRC research which is likely to deliver economic and societal impacts in the future
- The initiative helped to maintain the international competitiveness of UK bioscience research
- The initiative delivered long-lasting benefits to the UK bioscience community, which are still evident

## 4.1 Training and skills

57. One of the major achievements of the IGF initiative was an enhanced output of postdoctoral researchers and technicians trained in 'genomics' technologies and approaches. This was primarily achieved through the training of researchers directly employed on the grants. 123 staff were employed (not including casual staff), and their training helped to develop a core group of skilled researchers with 'genomics' expertise. The number of researchers employed by each consortium is shown below.

**Staff employed within each IGF consortium**

| **Consortium** | Research staff | Technical staff |
|---|---|---|
| ARK-Genomics | 2 | 5 |
| *Drosophila* | 9 | 11 |
| GARNet | 11 | 20 |
| *Brassica* | 6 | 15 |
| Cereals | 6 | 5 |
| COGEME | 15 | 9 |
| *Streptomyces* | 7 | 2 |
| **Total number**[1] | **56** | **67** |

[1] This is not the total number of positions funded by the IGF initiative. Some staff left during the course of the grants with others recruited to replace them.

58. The majority of staff employed on IGF grants moved to further posts in academia after working on the grant. 87% of research staff and 63% of technical staff remained in academia as their first employment destination, and several postdoctoral researchers subsequently secured permanent academic posts. A relatively small number pursued careers in industry (9% of research staff; 5% of technical staff). This was slightly disappointing, but not surprising considering the organisms being studied. The majority of staff remained in the UK (91% of research staff; 89% of technical staff).

59. Participation in the initiative also had a positive impact on grantholders' careers. For example, grantholders' work within the initiative raised their domestic and international profiles, and contributed to their high standing reputations within the research community.

60. In addition to the training provided to staff employed on the grant, the initiative also provided training opportunities for the wider research community. Some research groups with major facilities provided training in 'genomics' technologies to researchers and technical staff based in other laboratories or institutions. Information on the extent of these training activities or the benefits they provided for participants was patchy, but there were positive examples within the portfolio.

> The *Streptomyces* consortium developed a PCR-based targeting system for gene disruption, which was supplied freely to academic labs in the UK and internationally. Two practical courses were provided in its use at the John Innes Centre, which trained a total of 28 UK and international researchers. The courses were accompanied by a detailed manual, and copies of this were supplied to all users of the procedure. In addition, a number of visitors to the John Innes Centre were also trained in the technique.
>
> The COGEME consortium's Transcriptomics Research Facility (TRF) provided seven training courses in the use of microarray technology. Twenty two researchers participated, who were invited from groups who had applied to use the TRF facilities. The COGEME Proteome Research Facility at Manchester also provided training courses in mass spectrometry. Seven courses were run during the initiative, usually training 30 participants at a time.
>
> The ARK-Genomics consortium provided two training workshops on microarray experimental design and data analysis. The workshops were for twenty students each and ran for a week.

61. The initiative's strategy to build 'genomics' research capacity within BBSRC research communities by providing training to postdoctoral researchers and technicians was effective. However, the absence of a formal objective to provide training to postgraduate students was a weakness which delayed progress towards ensuring that the wider research community could recruit the skilled staff needed to conduct high-quality 'genomics' research.

62. It would have been useful to support postgraduate training within the initiative by funding studentships directly in association with IGF grants. The relatively long duration of IGF grants compared with standard responsive mode grants would have been ideal for this type of linkage. Greater support for postgraduate training within the initiative may have addressed some of the subsequent difficulties experienced by responsive mode grantholders when seeking to recruit staff with 'genomics' skills (see chapter 6, p. 52). Moreover, having studentships associated with IGF projects may have alleviated some of the problems from staff leaving projects before they were completed.

## 4.2 Interactions with industry

63. There was a relatively low level of interaction between IGF grantholders and industry within the context of the initiative. This was probably to be expected given the nature of the research and the organisms being studied. However, there was scope for a greater degree of interaction and knowledge exchange with industry, and it was a little disappointing that opportunities for interactions had not been fully explored.

64. One of the barriers to interactions between academia and industry was the mutual lack of awareness about each others' research activities. There were and continue to be shared research interests between academia and industry, and similar research to that in the IGF initiative was being conducted by industry at the time. BBSRC could have done more to inform industry of the initiative's activities, which may have helped to encourage exploitation and, possibly, to limit duplication. Potential interactions may also have been limited by the organisms being studied by the initiative as, for some consortia, there were relatively few companies to interact with in the corresponding industrial sector (e.g. the agricultural sector).

65. Although the overall level of interaction with industry was low, there were some encouraging signs that grantholders were establishing partnership links with industry. 24% of grantholders published papers with an industrial co-author and two received further funding from industry to develop their research. The work on the IGF initiative also contributed to collaborations with industry that were part of grantholders' wider research programmes.

Grantholders in the ARK-Genomics consortium developed multiple collaborations with industrial partners either as part of wider consortia or directly. One such collaboration was with Intervet, a company developing veterinary medicines and services, which resulted in £200K of industry funding. The grantholders also undertook research on behalf of several other companies, including a number of small and medium-sized enterprises.

Grantholders within the *Drosophila* consortium developed several industrial collaborations. They conducted informal microarray development work with Biorobotics, Genetix and Genomic Solutions. Other industrial collaborators included ABI, Amersham/GE, NonLinear Dynamics and Sigma.

A grantholder in the Cereals consortium, based at the University of Bristol, developed collaborations with Advanta Seeds. These followed directly on from the data generated in the IGF programme.

## 4.3 Networking, collaboration and community building

66. One of the objectives of the IGF initiative was to increase focus and coordination within BBSRC research communities by supporting collaborative methods of working. The initiative was extremely effective in meeting this goal. It helped to develop collaborative partnership links between grantholders, both within individual consortia and between different consortia. In addition, it had a very positive impact on networking and collaboration within the wider BBSRC research community. The initiative has had an enduring impact in promoting networking and strengthening research communities, the benefits of which are still evident today.

67. Interactions between consortium members were extensive and very positive. The collaborative partnership links led to the exchange of research materials and the development of databases, and resulted in a large number of joint publications and further funding. For some consortia, grantholders had not previously worked closely together and the initiative had a very positive role in fostering new partnership links. For other consortia, the initiative helped to strengthen existing collaborations. In all cases, the partnership links developed have proved to be long-lasting. Many grantholders continued to work together after the initiative and some of these collaborations formed the basis of contributions to a number of other UK and international 'genomics' projects.

> Grantholders within the *Brassica* consortium made important contributions to the UK-*Brassica* Research Community (UK-BRC), a group whose membership included a wide range of academic researchers, breeders and other end-users. The IGF initiative helped to raise the profile of UK *Brassica* research. UK-BRC currently plays a prominent role in the international *Brassica* research community and is involved in the Multinational *Brassica* Genome Project (MBGP). IGF grantholders are members of the MBGP Steering Group.
>
> The *Drosophila* research community was already well established at the outset of the IGF initiative. Grantholders' participation within the *Drosophila* consortium helped them to develop a strong international profile and enabled them to participate in other international projects. The work on *Drosophila* transcriptomics technologies contributed to the leading role played by the UK in the International Drosophila Array Consortium.
>
> The investment in the cereals IGF consortium galvanised the UK cereals community. IGF grantholders are active participants in the Monogram network, which provides a focus on UK grain and grass research.

68. The initiative played a very helpful role in promoting networking and collaboration within user communities, and a major outcome of the initiative was the strengthening of these wider research communities. At the outset, the strengths of the research communities working with organisms supported by the individual consortia were varied. Some communities were already well established, and the initiative played an important role in strengthening them further. Others were more nascent, and the initiative was crucial in promoting their establishment and development, bringing together disparate members of the community.

The GARNet consortium was an exemplary model of community building. It helped to foster a strong, collaborative *Arabidopsis* research community, and its achievements are recognised internationally. One of the consortium's strengths was the active involvement of the research community in determining research priorities. GARNet was awarded funding through responsive mode to coordinate its activities. The role of the coordinator proved to be very effective, and two further responsive mode grants for coordination activities were obtained.

The COGEME consortium brought together UK yeast and filamentous fungi research communities. It catalysed the transfer of functional genomics technologies from the highly tractable model organism *Saccharomyces cerevisiae* to more refractory fungi, including a number of plant pathogens. The IGF initiative played an important role in establishing a joint community of yeast and fungal researchers.

69. The initiative was also valuable in helping to foster a collaborative, open culture in the BBSRC research community. This has ultimately strengthened the quality of UK bioscience research and has contributed to the UK's reputation as a partner of choice for international collaboration.

## 4.4 Underpinning future research in the BBSRC remit

70. The IGF initiative was established at an early stage in 'genomics' research in the UK, with the intention of stimulating and underpinning further work which used new technologies and approaches. The initiative was very successful in this respect: it built capacity through good quality training, it delivered high-quality tools, resources, facilities and datasets, and it helped to strengthen and energise research communities. The initiative contributed to the substantial momentum in UK 'genomics' research at the time, and it enabled the wider research community to address questions of gene function and make use of the increasing amount of genome sequence data. The initiative played a very important role in embedding 'genomics' approaches into UK biological research, and (alongside other investments) led to 'genomics' having a prominent role in UK research activities.

71. The impact of the initiative on underpinning future research in the BBSRC remit is demonstrated by the high level of further funding achieved by grantholders, as well as the uptake of the tools, resources, facilities and datasets by other researchers. Further details of the impact of the IGF initiative in underpinning responsive mode research are provided in chapter 8, p. 61.

## 4.5 Economic and societal impacts

72. Economic and societal impacts are those impacts that relate to the overall objectives of BBSRC and would generally be expected to arise in the longer-term. The following economic and societal impacts would be expected to arise from BBSRC funding:
    - research findings are used for the public good (e.g. food security, industrial biotechnology, human health, medical research, government policy)
    - research contributes to the increased competitiveness of the UK economy (e.g. provision of skills and expertise, or contributions to new or improved products and processes)
    - income to the research community and 'UK plc' (e.g. from new technologies, intellectual property, spin-out companies)
    - the UK maintaining its high standing in biological sciences
    - public confidence in biological science research is maintained
    - BBSRC maintaining its role as a key funder of biological sciences

73. The research supported by BBSRC contributes to the public good in a number of ways. For example, it:
    - trains scientists in basic scientific research; many go on to work in industry and other sectors
    - generates a bedrock of fundamental scientific knowledge that underpins future research, commercial and other applications, and helps shape government policy
    - contributes to public engagement with science and supports science of public interest
    - helps to maintain a vibrant higher education sector that contributes to the local and national economies (e.g. through foreign students' fees), and to local communities

74. These impacts relate to how effectively the BBSRC is functioning and delivering the outcomes expected of publicly funded research. However, precise measurement and attribution of these impacts are difficult. It is particularly challenging to monitor the long-term impacts of programmes such as the IGF initiative, and there is a need to identify better mechanisms for capturing causal links between outputs arising today and grants awarded some time ago.

75. The IGF initiative was intended to be fundamental and underpinning, focused on the delivery of tools, resources, facilities and datasets for the wider community. As such, its main impacts were achieved through skilling the community rather than directly leading to economic benefits. To date, relatively few direct economic and societal impacts have been realised from the research conducted specifically within the IGF initiative. This is to be expected: the timelines are still too short to see the benefits and the IGF is still contributing to new outputs and outcomes. The major economic and societal impacts will be delivered by other research activities which were underpinned by the initiative. It is likely that the investment in the IGF initiative has compressed the time from the introduction of 'genomics' technologies and their eventual delivery of impacts.

76. All grantholders reported that their research had potential to contribute to the public good. For example, grantholders' research could make contributions to animal and human health, food security, mitigating climate change, and government policy:
    - Animal and human health: potential improvements to nutrition through the development of new plant varieties, techniques for engineering new antibiotics and improved production methods, greater understanding of basic processes of infections by a range of pathogens, and improvements in animal health
    - Food security: prospect of improved wheat breeding, development of higher yielding brassicas, improved methodology to enhance crop breeding programmes, and improved animal breeding to sustain increased yields.
    - Mitigating climate change: use of data for applications in drought tolerance in crops, and the selection of more energy efficient and less polluting farm animals
    - Replacement, refinement and reduction of animals in experiments: support for 'genomics' research in non-mammalian specie  encourages their adoption as alternative animal models
    - Policy development: contribution to methodologies for genetically modified plant safety assessment and registration, contribution to energy policy, and to data sharing policies

77. It was clear that without the investment in the IGF initiative, the UK's ability to address emerging global challenges would be weaker. The initiative contributed to maintaining a strong UK research base which is able to deliver solutions to problems such as food security and an ageing population. 'Genomics' technologies will continue to play an important part in tackling these challenges.

78. There was no specific programme of public engagement activities associated with the initiative. With hindsight, this was a weakness for such a high profile funding programme. If a similar research initiative were funded today, there would be greater emphasis on outreach.

## 4.6 International standing of UK bioscience research

79. The IGF initiative was important in maintaining the international competiveness of UK bioscience research. The investment in 'genomics' enabled BBSRC researchers to conduct high-quality research and raised the profile of UK bioscience communities. It enabled the UK to contribute to a wider set of 'genomics' tools and resources being developed by others, including the USA and other EU countries, and it positioned UK bioscience researchers so that they were able to contribute to and influence the development of other multi-national 'genomics' research programmes. Overall, the initiative made a valuable contribution to the international standing of UK bioscience research.

> A researcher in the *Streptomyces* consortium received further funding as part on an integrated EU project 'Actinogen'. They are coordinating this £9M project, which includes partners from nine different countries. The goal of the 'Actinogen' programme is to exploit overlooked genetic resources from diverse actinomycete bacteria for antibiotic development. The research is expected to lead to new technologies for antibiotic discovery and production, and will ultimately help to alleviate the current crisis in the treatment of multi-drug resistant pathogens.

The three consortia working on plant species (GARNet, *Brassica*, Cereals) helped to establish the UK's high international standing in plant 'genomics' research. The work of these consortia influenced the development of other EU plant science funding, including the €55M ERA-NET on Plant Genomics programme.

# 5. IGF initiative: Balance and coverage of the portfolio

## Summary

- The balance and coverage of the IGF initiative portfolio was appropriate
- It was appropriate to focus on a limited number of key organisms within the BBSRC remit
- The initiative was relevant to large sections of the BBSRC research community
- The initiative had a positive impact in enabling 'genomics' research funded through BBSRC responsive mode

## 5.1 Balance and coverage of the portfolio

80. The balance and coverage of the IGF initiative was good. The initiative focused on key groups of animal, plant and microbial species within the BBSRC remit, providing support for model organisms and species representative of key groups of organisms of economic significance.

81. On balance, it was appropriate to focus the initiative on a limited number of key organisms broadly representative of and relevant to BBSRC research communities and BBSRC's broader strategic vision. With limited financial resources available, investment in each consortium was still relatively modest. Indeed, the achievements of each consortium were very impressive considering the level of investment. The balance and coverage of the portfolio was also appropriate in the context of support for 'genomics' research from other Research Councils and funding bodies available at the time.

82. Although the initiative covered large sections of the BBSRC research community, a number of important species within the BBSRC remit were not supported. This was inevitable given the available resources. Whilst it might in principle have been useful to have developed 'genomics' tools and resources for a larger number of organisms, this would have diluted the investment in individual consortia too much and limited progress. Broader coverage of the BBSRC remit was expected to be delivered through responsive mode funding, through which researchers could seek support to develop 'genomics' tools and technologies for their organisms of interest.

## 5.2 Impact of the initiative on BBSRC responsive mode research

83. The initiative was very successful in engaging with the immediate community of researchers working with organisms supported by the initiative. These researchers benefited considerably from the initiative, using the 'genomics' tools, resources, facilities and datasets in their responsive mode research. Further details of the impact of the IGF initiative on responsive mode research are provided in chapter 8, p. 61.

# ‘Genomics’ research funded through responsive mode

# Executive Summary: ‘Genomics’ research funded through responsive mode

This section reports the findings of an independent evaluation of research incorporating ‘genomics’ technologies and approaches supported through responsive mode between 1999 and 2007. The objectives of the evaluation were to assess the quality of the research supported and to identify the major outcomes arising from it; to consider the balance and coverage of the portfolio; to examine the extent to which responsive mode research benefited from the Investigating Gene Function (IGF) initiative; and to identify ways to build on successes and address identified gaps and issues.

The Panel’s analysis was based on the final reports of a sample of 110 grants, as well as questionnaire responses which updated the final report for 81 of these grants.

## Key Conclusions

### 1. The support for ‘genomics’ research in responsive mode was timely and built on ‘genomics’ resources developed through other funding programmes

The evaluation covered a period when bioscience researchers were beginning to use ‘genomics’ techniques in their research, often for the first time. Responsive mode provided essential support for investigator-driven science and enabled the BBSRC research community to incorporate ‘genomics’ technologies and approaches into their own research programmes. The support for ‘genomics’ was timely and built upon the tools and resources being developed through the IGF initiative, as well as other UK and international funding programmes. It enabled ‘genomics’ technologies and approaches to become embedded within BBSRC science over the evaluation period.

### 2. The overall standard of the research funded through responsive mode was high

Grantholders utilised ‘genomics’ technologies and approaches within their responsive mode research projects to make exciting discoveries. The majority of grants met their original objectives and made useful contributions to their respective fields. A good proportion of the research was of an international quality. However, a mixture of less successful or less inspiring research was also funded, including a small number of grants which failed to meet their objectives. The overall performance of the research portfolio was good, if not quite as impressive as that of the IGF initiative.

## 3. The high standard of the research in the portfolio was reflected in the quality, quantity and range of the outputs arising from the grants

The research resulted in a good number of outputs including publications in high-quality journals, electronic database submissions, further funding to develop the research, new intellectual property, spin-out companies, and new collaborations. The overall quality and quantity of the outputs was good and was similar to that of BBSRC's wider responsive mode portfolio.

## 4. Grant performance was adversely affected by staffing difficulties as well as experimental, methodological and technological issues

The introduction of new 'genomics' technologies presented a number of challenges for the bioscience research community. Initially, there were shortages of skilled postdoctoral researchers with training in the use of 'genomics' techniques. As a result, grantholders experienced considerable difficulties with the recruitment and retention of skilled staff, and this often had an adverse impact on grant performance. Progress could also be hindered by experimental, methodological and technological issues associated with the use of new 'genomics' approaches.

## 5. Responsive mode provided a large number of postdoctoral researchers with training in the use of 'genomics' technologies and approaches

Responsive mode research provided a large cohort of postdoctoral researchers with experience of 'genomics' technologies. The 'genomics' skills of postdoctoral researchers improved notably during the course of the grants and this helped to address the skills shortages that were observed early on in the evaluation period. There were some gaps in the provision of 'genomics' skills training and, in particular, more emphasis should have been placed on postgraduate student training.

## 6. A good proportion of grantholders had established or developed partnership links with industry as a result of their grant

Grantholders used their responsive mode research projects to develop informal and formal partnership links with industry. These linkages were varied and included co-funding, studentships, informal discussions, in-kind support, joint funding applications, joint publications, licensing intellectual property, material transfer agreements, participation in academic-industrial consortia, and exchanges of people. The level of interaction with industry was higher than in the IGF initiative and the wider responsive mode portfolio. However, there was still scope for greater interaction and knowledge exchange between academic researchers and other stakeholders. Further facilitation by BBSRC might have helped to improve the number of linkages that were established over the evaluation period.

## 7. The research is likely to deliver economic and societal impacts in the future

Responsive mode research resulted in a good number of applications to secure intellectual property rights and contributed to the establishment or the development of nine spin-out companies. The research also had potential to deliver benefits to the wider public good including contributions to food security, human health, industrial biotechnology, animal health and welfare, the environment, and government policy in these and other areas. To date, relatively few of these benefits have been fully realised, but there were positive indications that the research was underpinning relevant future developments. For example, it was encouraging that grantholders obtained further support from other funding agencies to translate the knowledge gained through the responsive mode grant. As expected, the research was closer to delivering economic and societal impacts than that of the IGF initiative.

## 8. The balance and coverage of the 'genomics' portfolio was appropriate

There was considerable breadth in the coverage of the 'genomics' responsive mode portfolio. The research projects covered a wide range of subject areas within the BBSRC remit and used a variety of 'genomics' technologies and approaches. Researchers used responsive mode to address specific biological questions using 'genomics' techniques, as well as to develop new 'genomics' tools, resources and experimental approaches. Researchers primarily received support for basic research, although high-quality strategic and applied research was also funded. The portfolio covered a good range of organisms and systems, with an appropriate focus on research which could utilise the 'genomics' tools and resources developed through the IGF initiative and other funding programmes. However, the uptake of 'genomics' techniques may have decreased the popularity of some traditional experimental approaches (e.g. biochemistry, physiology) over the evaluation period.

## 9. The IGF initiative had a positive impact on responsive mode research

Grantholders whose research was closely aligned to the remit of an IGF consortium benefited considerably from the investment in the IGF initiative. They made use of IGF tools, resources, facilities and services, and were very positive about the impact of the initiative. However, as might be expected, grantholders whose research was less closely aligned to the remit of an IGF consortium received few direct benefits. There were indirect benefits which arose from the IGF initiative, but these were hard to separate from the effects of a global movement towards 'genomics' over the evaluation period. For example, it is likely that the IGF initiative encouraged researchers to seek support from responsive mode to develop 'genomics' tools and resources in their own organisms of interest.

## 10. The investment in ‘genomics’ research contributed to the international profile of UK bioscience

Responsive mode funding enabled UK bioscience researchers to participate in the global adoption of ‘genomics’ technologies and approaches. A high proportion of responsive mode grantholders established partnership links with international academics, which was a good indicator that UK research is highly regarded by the international scientific community. The UK’s strong international performance in bioscience was also illustrated by its excellent citations impact. The support for ‘genomics’ research provided by BBSRC and other funding agencies helped the UK to remain internationally competitive and enabled UK researchers to participate in and contribute to other international funding programmes

## 11. The portfolio of responsive mode ‘genomics’ research provided good value for money

Over the evaluation period, responsive mode supported ‘genomics’ research of a high standard which produced good outputs and outcomes. The support enabled a large proportion of the BBSRC research community to use ‘genomics’ technologies and approaches, and benefited research from across the BBSRC remit. ‘Genomics’ research underpinned future scientific developments in areas such as systems biology, and in the future is likely to deliver important economic and societal impacts. Overall, the investment in ‘genomics’ research represented good value for money for BBSRC.

# 6. Responsive mode: Standard of research

## Summary

- The overall standard of research within the responsive mode 'genomics' portfolio was high
- The research produced a good number of publications in high-impact and prestigious journals, as well as submissions to electronic databases
- A good proportion of grantholders developed intellectual property and several established or developed spin-out companies
- A very good number of academic partnerships links were established or developed, particularly with the USA and the rest of Europe
- Researchers were successful in obtaining further funding to continue or develop the research
- Grant performance was negatively affected by staffing difficulties as well as experimental, methodological and technological issues
- A small number of less successful and less inspiring research projects were funded over the evaluation period

## 6.1 Context of the evaluation

84. Responsive mode provided the first opportunity for many scientists within the BBSRC research community to use 'genomics' technologies and approaches in their own research; 62% of grantholders reported that the sample grant was the first time they received funding to conduct 'genomics' research. As might be expected, the adoption of a novel set of rapidly developing technologies created new challenges for researchers. Nevertheless, grantholders were able to incorporate 'genomics' technologies into their research programmes and use them to address biological questions in exciting and innovative ways.

## 6.2 Research quality

85. The overall quality of the research was high. Grantholders used 'genomics' technologies and approaches within their research to make exciting discoveries. The majority of projects met their objectives and made useful contributions to their respective fields of study. Some very talented and productive researchers were supported, and a good proportion of research projects were of an international standard.

Researchers at Imperial College London studied the population and evolutionary processes which are responsible for shaping the genome of *Saccharomyces paradoxus*, a close but undomesticated relative of brewer's yeast. The exploratory project involved sequencing an entire chromosome in twenty individuals of *S. paradoxus* and led to the unexpected discovery that the centromere is the most rapidly evolving region of the chromosome. The study acted as a pilot for the full genome resequencing of yeasts, which was itself a pilot for the '1000 genomes' project in humans. The research also informed the grantholder's analogous programme of population genomics of the malaria-transmitting *Anopholes* mosquito funded by the Bill and Melinda Gates Foundation 'Grand Challenges in Global Health' initiative.

A project at the University of Oxford investigated intracellular signalling cascades within blood platelets using proteomics technologies. Blood platelets are small cells which are important for blood clotting and have a role in thrombotic diseases such as stroke and myocardial infarction. The research generated a two-dimensional proteome map of human platelet cells and led to the identification of novel platelet proteins important for platelet activation, some of which may eventually serve as drug targets for thrombosis and heart disease.

86. 78% of the final reports were graded either 'A' or 'B' by Research Committee assessors; 32% were graded 'A'. The Panel generally agreed with this distribution of grades, noting that the majority of grants had performed well and produced a good number of outputs. The high overall quality of research in the 'genomics' portfolio was similar to that of the wider responsive mode portfolio. However, it was not quite as impressive as that of the IGF initiative grants.

## 6.3 Research outputs

87. The general high standard of the research in the portfolio was reflected in the quality, quantity and range of outputs arising from the sample grants. The outputs included papers in prestigious journals, electronic database submissions, new intellectual property, nine spin-out companies, further funding to develop the research and the development of academic partnership links.

88. Data on research outputs were collected from final reports and questionnaire responses from the sample of 110 grantholders. The figures are likely to underestimate the total outputs from the sample grants, because while they include data from the final reports for all 110 grants, they only include survey responses for the 81 grantholders who returned the questionnaire. However, there was also a degree of over reporting by grantholders, and some outputs appeared to be primarily the result of other funding. Similar observations were made in other evaluations of the Research Committee responsive mode portfolios.

A collaboration between researchers at the University of East Anglia, University of York and the Wellcome Trust Sanger Institute led to production of the complete genome sequence of the bacterium *Rhizobium leguminosarum*. Rhizobia are soil bacteria with significant importance to agriculture, allowing many crops to be grown without nitrogenous fertiliser, an energy expensive and potentially polluting agent. The sequence is freely available and provides an important resource for agricultural and environmental research in symbiotic nitrogen fixation.

Scientists at the Institute for Animal Health and Welcome Trust Sanger Institute produced a genome sequence of *Eimeria tenella*. This parasite infects the intestinal track of poultry and causes coccidiosis, one of the economically most important diseases in modern poultry production; the estimated total cost of coccidial infections in the UK is at least £42 million per year. The availability of the *E. tenella* genome sequence will help to combat this disease. It also has potential to contribute to advances in the research of related parasites which cause disease in humans (e.g. malaria, toxoplasmosis, cryptosporidiosis).

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

96. 65% of grantholders stated that the research supported by their grant had resulted or could result in a novel product, process, resource, tool or technology. The types of outputs varied widely, but included assays, constructs, databases, datasets, genome sequences, libraries, methods, microarrays, mutant lines, reagents, transgenic lines and software. The proportion of grantholders reporting such outputs was good, and was higher than in other responsive mode portfolio evaluations (an average of 45%). However, the Panel noted that it was unlikely that all of the outputs described as 'likely to arise in the future' would be realised.

97. The reported users of the outputs were primarily other academic researchers. Other users included industry (e.g. agricultural, biotechnological, medical, pharmaceutical), biomedical researchers, veterinary clinicians and diagnostic laboratories. The tools and resources were made readily available to the wider community through publications (peer-reviewed journals or online databases), stock centres or by direct request. A few outputs were not initially made accessible, to protect intellectual property.

A grant at University of Leeds developed resources for 'genomics' research in the moss *Physcomitrella*. The project produced a range of tools and resources which were made available to the research community including DNA sequences, EST collections, a genomic BAC library and a cDNA microarray. The grantholders also organised three one-week residential workshops to provide training in the techniques they had developed. One outcome of the project was the more widespread adoption of *Physcomitrella* as a model organism in the international plant science community.

98. The Panel expressed some concern about the longer-term accessibility, sustainability and maintenance of resources generated through responsive mode funding. The extent to which resources were being formally maintained within stock centres was not clear. It was likely that many resources were stored within grantholders' own laboratories and

there were risks that they could be lost (e.g. if a freezer malfunctions, or if the grantholder moves institutions or retires). BBSRC may wish to consider more carefully how resources developed through responsive mode research should be maintained.

## 6.7 New intellectual property and spin-out companies

99. The proportion of researchers who developed intellectual property (IP) as a result of their grant was commendable. 16% of grantholders applied to secure IP as a result of their grant or used their grant's research to develop existing IP. A further 7% were likely to apply to secure IP in the future. Six grantholders (5%) stated that their IP had been licensed to others, and two (2%) secured income as a result. In previous evaluations of responsive mode research 10% of grantholders applied to secure IP, 2% licensed their IP to others, and 1% had secured income.

> Researchers at Oxford Brookes University and the NERC Centre for Ecology and Hydrology conducted research on the use of insect viruses (baculoviruses) as biotechnological tools for the production of proteins. The research addressed the bottlenecks that were limiting the high throughput use of the baculoviruses expression systems. The researchers developed a suite of intellectual property which was subsequently licensed to a spin-out company, Oxford Expression Technologies, and incorporated into their commercial products.

100. Nine grantholders (8%) stated that the research supported by their grant contributed to the formation or further development of a spin-out company, which is higher than in most other BBSRC Research Committee responsive mode portfolios. The spin-out companies covered a range of sectors, including agriculture, biotechnology, pharmaceuticals, veterinary diagnostics, as well as services and the supply of reagents. Seven of these companies were trading at the time of the evaluation surveys.

> Researchers at the University of York and their collaborators investigated techniques for the production of mammalian embryos, with the aim of improving assisted conception procedures in humans and domestic animals. The research contributed to the growth of a spin-out company, Novocellus, which is developing technologies for use in human in vitro fertilisation (IVF) treatment. Novocellus has developed a system for selecting embryos likely to lead to a successful pregnancy and this is expected to lead to a 25% increase in the clinical pregnancy rate for IVF as well as a reduction in health risks for the mother and baby.
>
> Scientists at the University of Glasgow identified proteins in milk that can be used as markers for mastitis, a major disease within UK dairy herds. They also optimised a method for proteomic investigation of milk. The research has the potential to lead to better diagnostics for mastitis and reduced milk losses in herds. It contributed to the development of a spin-out company, ReactivLab, which specialises in the diagnosis and prognosis of animal illnesses.

101. Although a good proportion of grantholders had developed IP as a result of their 'genomics' research, there was potential for greater exploitation of the research within the portfolio. It was slightly disappointing that more grantholders had not sought to develop and secure the IP that arose from their research projects, although the Panel would not wish to encourage grantholders to apply for IP rights inappropriately. There are risks in applying to secure IP at too early a stage when it has limited commercial

value. The opportunities to develop IP will also vary depending on research area and the nature of the project. However, on balance, greater exploitation of the research within the portfolio might have been possible.

## 6.8 Further funding to develop the research

102. The level of further funding received by grantholders was good; 56% of grantholders obtained at least one further grant to continue or develop the research supported by the original grants. This was very similar to the results reported in other Research Committee responsive mode portfolio evaluations.

103. Funding was received from a broad range of sources including BBSRC, the Wellcome Trust, the EU, industry, the Medical Research Council, the Engineering and Physical Sciences Research Council, the Bill and Melinda Gates Foundation, Cambridge Isaac Newton Trust, CNPq (Brazil), the Danish government, Defra, Deutsche Forshungsgemeinschaft (Germany), the Foreign and Commonwealth Office, the Gatsby Charitable Foundation, the Higher Education Innovation Fund, the Scottish Funding Council, and university commercialisation funds. Researchers were using BBSRC responsive mode to underpin more strategic research in their research programme. Many of the non-BBSRC funding sources support research that is more translational than that funded by BBSRC. 15% of grantholders reported that their sample grant had directly underpinned a more strategic research project in their research programme.

Researchers at the University of Manchester used a 'genomics' approach to study the mechanisms underlying the stability of cells used for the production of complex protein-based drugs. They received further funding from BBSRC's Bioprocessing Research Industry Club to model how many different factors in the cell interact to influence the production of the therapeutic proteins. The research may eventually contribute to more efficient production of these proteins and lower drug costs.

Researchers at the University of Sheffield used transcriptomics techniques to study the resistance of the model plant *Arabidopsis thaliana* to *Striga*. This parasitic weed is considered to be the major biological constraint to cereal production in sub-Saharan Africa and threatens the livelihoods of some of the world's poorest farmers. The grantholder obtained further funding to develop the research from the BBSRC / DfID 'Sustainable Agriculture for International Development' programme. The follow-on research aims to examine the molecular genetic basis for *Striga* resistance in cereals, with the ultimate aim of developing resistant cultivars of crops such as sorghum, maize, millet and rice.

Researchers at Imperial College London developed a regulated expression system for use in mycobacteria which allows scientists to switch specific genes on and off. The grantholder subsequently received funding as a member of a consortium supported by the Bill and Melinda Gates Foundation 'Global Health' programme. This further research aims to identify the molecular signatures of latent tuberculosis in human tissues and target them with novel drugs. It involves partners from the UK, Mexico, Singapore, South Africa, South Korea and the USA.

An early-career researcher at the University of Sheffield received a New Investigator[4] grant to study bacterial aggregation and biofilm formation, processes which are of great significance in biotechnological, environmental and medical industries. The research was at the engineering / biological systems interface and used proteomics to investigate the physiological response of bacteria to cell-cell communications. The project enabled the researcher to establish their research programme and contributed to the subsequent award of an Advanced Research Fellowship from EPSRC.

104. 6% of grantholders received further funding from the EU to continue or develop the research in their sample grant. It was encouraging that UK researchers had obtained this support, as it is a very competitive source of funding. The success of grantholders in obtaining EU funding was a strong indicator that high-calibre researchers had been supported through responsive mode.

Scientists at the University of Nottingham developed a powerful set of molecular tools to enable the exploitation of genome sequence information from *Clostridium* species. These bacteria include the human pathogen *C. difficile* (associated with hospital infections) as well as industrially important species used in the production of chemical fuels. The grantholder obtained further funding from the EU 'Systems Biology of Microorganisms' programme to participate in a consortium which is examining the production of butanol by *C. acetobutylium*. They also obtained support from the Medical Research Council to investigate the molecular basis of virulence in *C. difficile*.

## 6.9 Academic partnership links

105. An impressive number of academic partnership links were established or developed as a result of the research. 91% of grantholders reported that their grant led to new or improved academic partnership links with academics in the UK or overseas; 77% established or developed a formal collaboration (e.g. joint publication or joint grant proposal).

106. The number of linkages to overseas academics was also very good. 80% of grantholders reported that their grant led to new or improved partnership links with overseas academics; 70% established or developed a formal research collaboration. There were particularly strong partnership links with the USA and other European countries. For example, 33% and 31% of grantholders reported new or improved partnership links with academics in the USA or the rest of the EU, respectively.

107. The level of interaction with international academics was a good indicator that UK research is highly regarded and that the UK is a preferred country for collaboration. The international Panel members noted that UK science groups are viewed as being accessible by the international science community, and that this open-culture has been fostered by funding programmes such as the IGF initiative.

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

## 6.10 Less successful grants

108. Although the overall standard of the research was good, the portfolio also contained a mixture of less successful or less inspiring research. In particular, a small number of projects were funded over the evaluation period, which failed to meet their objectives or resulted in very few outputs. 22% of grants were graded as 'C' or 'D' from their final reports, and 9% did not result in an original research articled being published[5]. This was disappointing, although the proportion of underperforming grants was in line with other responsive mode research funded during this period.

109. The degree of underperformance in the less successful projects was varied. Some projects only narrowly failed to meet their objectives, whereas others had failed by a substantial margin. The Panel felt that a relatively high proportion of the less successful projects in the 'genomics' portfolio fell within the latter category compared with the wider responsive mode portfolio. This was usually a consequence of the substantial technical difficulties associated with the establishment of new 'genomics' technologies, rather than poor project management. Moreover, given the novelty of the research approaches being used, a comparatively higher failure rate was justifiable.

110. There was evidence that the standard of 'genomics' responsive mode grants had improved over time; fewer sample grants failed to meet their objectives in later years of the evaluation period. This may have been because researchers were becoming more familiar with the use of 'genomics' technologies and the technologies themselves were improving. In addition, the application success rate fell over the evaluation period, reducing the number of less competitive applications which were funded.

## 6.11 Issues affecting grant performance

111. A substantial proportion of grantholders (45%) experienced issues which affected the performance of their grant. The main problems were staffing difficulties and experimental, methodological or technical issues. Other grants were affected by a change in research direction caused, for example, by the publication of new data by other researchers. In most cases, researchers were able to overcome the problems and meet their objectives. However, in a small proportion of grants, these issues had a very detrimental effect on performance.

### Staffing difficulties

112. Staffing difficulties were the most prominent issue which affected grant performance. These included difficulties with recruiting staff with suitable skills and experience, staff temporarily stopping work during the grant, and staff leaving during the grant. 28% of grantholders reported that they had been affected by staffing difficulties; for researchers who identified that their project was less successful than anticipated, this figure was 57%.

113. Issues with recruitment and retention of staff were identified in other evaluations, but they appeared to be more prominent within the 'genomics' responsive mode portfolio. At the beginning of the evaluation period, there was no existing skill base of postdoctoral researchers or technical staff trained in 'genomics' techniques to draw upon, and once staff were trained they became more attractive to other employers,

[5] Ten grantholders reported that no original research articles had arisen as a result of their grant. Of these, six did not return a questionnaire to update their final report.

including those in industry, which affected staff retention. A higher proportion of responsive mode grants were adversely affected by staffing difficulties than IGF initiative grants. Responsive mode projects were more vulnerable to staffing issues, as they usually employed a single postdoctoral researcher.

114. One of the expected outputs of the IGF initiative was an increased number of postdoctoral researchers and technicians underpinning 'genomics' research. Whilst this goal was achieved, it was clear that the number of trained individuals remained insufficient to meet the wider demand from within the BBSRC research community.

### Experimental, methodological and technical issues

115. 18% of grantholders reported that project performance had been affected by experimental, methodological or technical issues; for researchers who identified that their project was less successful than anticipated, this figure was 64%. These issues were primarily associated with establishing the use of 'genomics' techniques. In some cases the techniques did not work, whereas in others they took much longer to establish than first anticipated.

116. It is expected that grantholders will experience experimental, technological or methodological issues when incorporating new technologies into their research programme. Indeed, a small degree of failure within the research portfolio is a good indicator that innovative, adventurous and exploratory research is being supported. However, the Panel felt that a few grants were overambitious or premature at the outset, and that, at the time, the technology was not sufficiently established to enable the proposed research to be conducted.

117. Several grants would have benefited from an increased duration. In some cases the standard three year grant was not sufficient to establish the use of a new technology or for the project to realise its potential. The Panel noted that the duration of a few grants had been cut by Research Committees at the award stage. This usually had a detrimental effect on the project and ultimately did not provide value for money for BBSRC.

## 6.12 Final reporting

118. The quality of reporting was very variable. Some reports were well written, clearly and concisely explaining the objectives and achievements of the research. However, a substantial proportion of reports were poorly written: they failed to explain the purpose or outcomes of the research, they left whole sections incomplete, or they included a scientific report which was too long. The lay summaries for many grants were particularly poorly written.

119. In general, the Panel agreed with the final report grades that were assigned to grants by Research Committee assessors. However, across the portfolio as a whole there was some concern that the grading had been slightly generous. This was most notable for final reports at the 'B/C' or 'C/D' border, which were sometimes given the higher grade when the lower one would have been more appropriate.

# 7. Responsive mode: Research impacts

## Summary

- Responsive mode provided a large cohort of postdoctoral researchers with training in the use of 'genomics' technologies and approaches, although there was insufficient emphasis on postgraduate student training
- The level of academia-industry interaction within the portfolio was good
- The research has potential to deliver benefits to the wider public good including contributions to food security, human health, industrial biotechnology, animal health and welfare, the environment and government policy
- There were positive indications that the research was underpinning further developments that are likely to deliver economic and societal impacts in the future
- Support for 'genomics' research made an important contribution to the UK's strong international standing in the biosciences

## 7.1 Training in 'genomics' skills and techniques

120. The training of postdoctoral researchers, technical staff and postgraduate students is a vital function of BBSRC funding. It provides the skilled scientists who conduct research in academia and industry, as well as contributing scientifically-literate personnel to the wider economy. During the evaluation period there was a shortage of skilled postdoctoral researchers with experience of 'genomics' technologies, and a large proportion of researchers reported difficulties with the recruitment and retention of staff. Responsive mode funding provided a cohort of postdoctoral researchers with training in 'genomics' technologies and this was a very important outcome of the grants.

121. A large proportion of postdoctoral researchers were relatively unskilled in the use of 'genomics' technologies at the start of their grant. 49% of grantholders stated that their RA's skills in 'genomics' were only fair or poor at the outset of the grant. The 'hands on' training provided through responsive mode projects enabled RAs to improve their 'genomics' skills. 68% of grantholders reported a notable improvement in their RA's 'genomics' skills over the lifetime of the grant. 88% stated that these skills were good or very good by the end of the grant.

122. The training opportunities provided through responsive mode complemented those of the IGF initiative. The IGF initiative provided very good training in 'genomics' technologies and approaches for select groups of postdoctoral researchers and technicians. In addition, the research from the IGF initiative gave rise to publications and patents involving technology development and applications, which also assisted in increasing the skills level, 'know how' and methods of using 'genomics' technologies. Responsive mode enabled a larger cohort of postdoctoral researchers to gain experience with 'genomics' and helped to address the skills shortages reported during the evaluation period. The postdoctoral researchers employed on the grants subsequently pursued careers in academia and industry where they utilised their 'genomics' skills, and contributed to the training of the next generation of bioscientists.

A project at the Sainsbury Laboratory, University of East Anglia, used transcriptomics techniques to identify genes involved in a symbiotic relationship between plant roots and fungi. The postdoctoral researcher on the project went on to lead the molecular breeding team in the plant genome facility at the University of York.

A grant at the University of Glasgow provided an Affymetrix array service for the UK Drosophila community, complementing the glass microarrays developed through the IGF initiative. The postdoctoral researcher on the grant built a worldwide reputation for their Drosophila array output and subsequently became a member of the research staff at the University running Affymetrix and Solexa services.

123. There were issues relating to 'genomics' skills training that were not addressed by either the IGF initiative or responsive mode funding. In particular, there was insufficient emphasis on providing training for postgraduate students. Postgraduate training in 'genomics' could have been improved by funding studentships in association with research grants. In addition, many grantholders were themselves relatively inexperienced with 'genomics' techniques at the time, and by the end of the grants, much of the 'genomics' expertise was held by postdoctoral researchers rather than grantholders.

## 7.2 Interaction with industry

124. 45% of grantholders reported that their grant led to new or improved partnership links with industry in the UK or overseas. These partnership links were varied and included co-funding, CASE studentships[6], informal discussions, in-kind support, joint funding applications, joint publications, licensing of intellectual property, material transfer agreements, participation in academic-industrial consortia and exchanges of people.

125. 32% of grantholders established or developed a formal collaboration with industry as a result of the grant (e.g. co-funding, joint publication, joint grant proposal); 21% established or developed a formal collaboration with UK industry and 10% developed a formal collaboration with overseas industry (primarily with companies based in other European countries or the USA). 14% of grantholders published papers with an industrial co-author. 17% reported specific examples of knowledge exchange with non-academic end-users.

Researchers at the University of Nottingham used a proteomics approach to investigate the mechanism of action of specific isomers of conjugated linoleic acid (CLA) on lipid metabolism. CLAs exists naturally as part of our diet and have been suggested to have a number of possible health benefits. During the project, the grantholder took a four month sabbatical to work at AstraZeneca developing proteomic technologies. The grantholder also established a collaboration with Dairy Management Inc. in the USA.

[6] CASE studentships are designed to allow postgraduate students to receive high quality training in collaboration with an industrial partner. Students undertake research on a subject selected and supervised jointly by academic and industrial partners.

Scientists at Imperial College London investigated long-distance shoot branching signals in two model plant species, pea and *Arabidopsis thaliana*. They developed metabolomics methodologies which enabled them to detect unknown compounds of low abundance. The projected contributed to a CASE studentship with Advanced Technologies Cambridge Ltd, a company with interests in crop improvement, product characterisation and toxicological evaluation.

126. Grantholders established or developed partnership links with at least 45 different companies, including multi-nationals, small and medium-sized enterprises, and small start-ups. Several sectors were represented, including agriculture, animal health, biotechnology, food and drink, healthcare, pharmaceuticals, nanotechnology, supply (e.g. instrumentation, reagents, software) and technical services. However, there was some concern that individual sectors were often represented by a relatively small number of companies.

127. The level of academia-industry interactions was good, especially as much of the portfolio was basic research at a relatively early stage of development. The level of interaction was higher than reported in most other responsive mode portfolio evaluations, although there was still scope for a greater level of collaboration between grantholders and industry. Over the evaluation period, responsive mode supported a relatively low number of LINK[7] grants or Industrial Partnership Awards[8] (IPA); three stand-alone LINK grants and no IPAs were funded which used 'genomics' approaches. The Panel noted that the Applied Genomics LINK programme and Exploiting Genomics initiative were running over the evaluation period, and these may have absorbed many of the direct research collaborations with industry. For example, twenty one projects were funded through the Applied Genomics LINK programme.

A LINK project between researchers at the University of Cambridge and Bayer CropScience examined the role of specific transcription factors in the control of the cell cycle, cell growth and differentiation. The industrial partner provided funding to conduct transcriptomics analysis using Affymetrix chips. The project led to a number of good publications, two of which have been very highly cited.

128. The nature of academia-industry partnership links differed depending on the industrial sector. For example, interactions in the pharmaceutical or human nutrition sectors often involved direct funding from industry, whereas interactions in the agricultural sector tended to be more collaborative and were more likely to involve in-kind support. There were also differences within the portfolio depending on research area. For example, within the plant sciences, researchers working with crop species had developed good links with industry, whereas there were many fewer partnership links with researchers working with model plant species.

129. Three grantholders (3%) reported that their project involved a formal collaboration with industry but their partner's priorities changed during the course of the grant (e.g. the industrial partner was taken over by another company). As a result, some aspects of the projects could not be completed as intended, and the exploitation of the research was

[7] The national LINK scheme promotes academic-industrial collaboration in pre-competitive research. Projects are typically funded 50:50 by industry and government. BBSRC contributes around £3M to LINK projects.
[8] Industrial Partnership Awards are science-led, responsive mode grants were an industrial partner contributes in cash (not 'in-kind') at least 10% of the full economic cost of the project.

delayed. Although this was disappointing, it was probably unavoidable, and the grantholders worked hard to overcome these setbacks.

130. There are a number of barriers which limit the level of knowledge exchange and collaboration between academia and industry. For example, it is often difficult for academics and industrialists to make initial contacts with one another. The development of partnership links requires support from organisations such as the Research Councils, and greater facilitation over the evaluation period may have increased the number of formal collaborations. Looking forward, industry's ability to make cash contributions to programmes such as LINK and IPAs is likely to be restricted in the current economic climate, although the 'shared risk' these schemes offer remains appealing to industry.

## 7.3 Economic and societal impacts

131. The research within the 'genomics' responsive mode portfolio was primarily basic, underpinning research, which provides a bedrock of knowledge for future developments. To date, insufficient time has passed to realise the full benefits from the research and, as such, it is still too early to judge its wider impacts. However, a substantial proportion of research within the 'genomics' portfolio had potential to deliver economic and societal impacts, and the indicators that this would happen were good.

132. 67% of grantholders reported that their research had potential to deliver benefits to the public good including contributions to food security, human health, industrial biotechnology, animal health and welfare, the environment, and government policy. The main areas where grantholders felt they were likely to contribute were human health and food security; 43% and 28% of grantholders, respectively, stated that their research could make contributions to these important areas of strategic priority for BBSRC.

Scientists at the University of Leeds investigated the genes involved in interactions between nematode pests and plants using a functional genomics approach. Parasitic nematodes represent one of the major biotic causes of yield loss in crops worldwide and are estimated to cost over £80 billion annually. The project identified nematode genes that are activated during the initial infection and used RNA interference to show that they are involved in the infection process. The grantholders obtained further funding to develop plants with sustainable resistance to nematode pests. In particular, they obtained a BBSRC / DfID 'Sustainable Agriculture Research for International Development' grant to exploit their findings in the development of nematode resistant plantain crops for African subsistence growers.

Researchers at Aberystwyth University and the University of Manchester used transcriptomics and proteomics techniques to investigate dormancy in mycobacteria, a group of bacteria which includes the causative agent of tuberculosis (TB). The results from this research and the grantholder's wider research programme have been incorporated into the Aeras Global TB Foundation vaccine development programme.

A collaboration between researchers at the University of Bristol and Rothamsted Research examined the effects of different types of nitrogen fertiliser on wheat. Using a transcriptomics approach, the researchers discovered that there were differences in gene expression in grain endosperm when nitrogen is supplied in either organic or inorganic form. The science made an important contribution to the wider debate surrounding organic and non-organic food production.

133. Six grantholders (7%) stated that their research had potential to contribute to the replacement, refinement and reduction of animals in experiment. 'Genomics' research contributed to an increased level of understanding of non-mammalian organisms (e.g. *Caenorhabditis elegans*, chicken embryos, *Drosophila*, zebrafish), and was encouraging their adoption as alternative animal models. In addition, improved bioinformatics tools and analysis were reducing the amount of 'wet' research that needs to be conducted.

134. When 'genomics' technologies were first introduced, there was considerable anticipation about the impact that they could deliver. For example, there were high expectations from academia and industry that 'genomics' would enable rapid identification of novel targets for exploitation. Realising the potential benefits of 'genomics' research has proved to be more complex than first envisaged and, to date, relatively few impacts have arisen from the portfolio. Nonetheless, the first tranches of 'genomics' research were essential for underpinning future developments and it is likely that later tranches of funding will deliver important impacts. This will be aided by the use of more sophisticated approaches and more powerful bioinformatics tools (e.g. systems biology).

135. There were positive indications that the research had underpinned future developments. Grantholders developed intellectual property and used their research to establish or develop 'spin-out' companies. They had also obtained further support from other funding agencies to translate or apply the knowledge gained through the responsive mode grant. Overall, and as expected, the research was closer to delivering economic and societal impacts than that of the IGF initiative.

## 7.4 International standing of UK bioscience research

136. Support for 'genomics' research within responsive mode and the IGF initiative had energised the BBSRC research community to conduct international quality science. It was not feasible in the context of this evaluation to generate specific international comparison data for 'genomics' research. However, the Department for Business. Innovation and Skills publishes a number of Public Service Agreement target metrics for UK bioscience research as a whole. The metrics compare the performance of the UK in biosciences with other major research countries using bibliometric data from ISI National Science Indicators. The most recent data were published in 2009[9] and show the UK to be ranked very highly for the quality of its bioscience research. The UK was ranked second (behind the USA) for its share of citations in the biosciences, and was ranked first in citation impact (ratio of citations to publications).

[9] www.bis.gov.uk/policies/science/science-funding/science-budget/uk-research-base

# 8. Responsive mode: Balance and coverage of the portfolio

## Summary


- The overall balance and coverage of the portfolio was good
- The research covered a wide range of subject areas within the BBSRC remit and used a variety of 'genomics' technologies and approaches
- Researchers used responsive mode to address specific biological questions using 'genomics' techniques, as well as to develop new 'genomics' tools, resources and experimental approaches
- The portfolio was primarily basic research, although high quality strategic and applied research was also funded
- A substantial proportion of the portfolio was focused on model organisms, and this was partly driven by the availability of 'genomics' tools and resources
- The IGF initiative had a positive impact on responsive mode research
- Grantholders were generally very positive about BBSRC's support for 'genomics' research over the evaluation period


## 8.1 Balance and coverage of the portfolio

137. The Panel reviewed the balance and coverage of the portfolio based on the data from 222 'genomics' grants with start dates between 2000 and 2005. The research covered a wide range of subject areas from across the BBSRC remit and used a variety of 'genomics' technologies and approaches. The responsive mode research built on the tools and resources provided by the IGF initiative. However, whereas the IGF initiative was necessarily focused on a limited number of key organisms, responsive mode provided much broader coverage of the BBSRC remit.

138. All seven former BBSRC Research Committees provided support for 'genomics' research projects although, as might be expected, the number of projects within the Biomolecular Sciences Committee remit was relatively low. The largest numbers of 'genomics' projects were funded by the Animal Sciences, Genes and Developmental Biology and Plant and Microbial Sciences Research Committees.

139. 78% of grants sought to address specific biological questions using 'genomics' technologies as the primary objective of the grant; 22% sought to develop new 'genomics' tools, resources and experimental approaches. This was an appropriate balance, and it was good that responsive mode enabled researchers to develop 'genomics' resources for their own organisms of interest, thereby increasing the availability and accessibility of 'genomics' resources to scientists from across the BBSRC research community. Within the portfolio, there was greatest support for grants which used transcriptomics, proteomics and functional genomics technologies; fewer grants were funded which used metabolomics (which was an emerging area at this time) or involved genome sequencing.

Research at the University of Aberdeen examined the events which occur when the animal parasitic nematode *Trichenella spiralis* infects muscle cells. The researchers used proteomics techniques to identify proteins excreted or secreted by the nematode which change the behaviour of the muscle cell. The approach was very successful and identified thirteen different proteins, some of which had multiple isoforms.

Scientists at the University of Dundee and the University of Sheffield collaborated to develop resources for functional genomics in chicken. They researchers produced robust tools for generating gene knockdowns in chick embryos, and these were made publicly available through ARK-Genomics. The genetic tools developed in the project will encourage researchers to use chick embryos as an alternative to mouse embryos for the analysis of vertebrate development, and will thereby contribute to the replacement, refinement and reduction of animals in experiments.

140. The balance of support for basic, strategic and applied research[10] within the 'genomics' portfolio was good. 66%, 32% and 2% of grants were classified as basic, strategic or applied, respectively, and high quality research was funded in each category. The Panel welcomed the strong support for basic research in responsive mode, and noted that this should be maintained. Basic research underpins future discoveries and developments which will have benefits for the UK. The industrial members of the Panel also noted the high value industry places on basic academic research.

141. Responsive mode provided support for research using animals (farm animals, model animals, humans), microorganisms (bacteria, yeast, fungi, protists), plants (crop plants, model plants), and viruses (animal and plant diseases). A large proportion of the portfolio was focused on model organisms. This was acceptable at the time, and was partly driven by the availability of 'genomics' tools and resources. Looking forward, there should be a greater emphasis on research using organisms which have more direct relevance to end-users. It is also important to translate the most promising research using model organisms to more strategic or applied systems, although it is recognised that this is not necessarily straightforward.

142. The Panel noted that the adoption of 'genomics' technologies had some negative impacts on the balance and coverage of the wider BBSRC research portfolio. More traditional experimental approaches, such as biochemistry and physiology, became less popular over the evaluation period. In recent years, the power of these traditional experimental approaches to complement 'genomics' approaches has been more readily recognised and they are used to validate the results obtained by genomics approaches. Research projects are now more likely to adopt an integrative approach, using a range of techniques to address biological questions.

[10] Researchers can receive support for basic, strategic and applied research grants through responsive mode:
- **basic**: research that is 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

## 8.2 Impact of the IGF initiative on responsive mode research

143. The IGF initiative had a positive impact on responsive mode research. As might be expected, researchers whose work was more closely aligned to the remit of the IGF initiative benefited the most. 38% of grantholders stated that they made use of IGF initiative resources or services. This aligned well with the 39% of sample grants which used organisms that were covered by the initiative.

144. The specific benefits of the IGF initiative on individual responsive mode grants could not be easily ascertained from grantholders' final reports. However, grantholders reported a variety of benefits from the initiative in evaluation surveys, which included that the IGF had:
    - provided easier, faster and subsidised access to 'genomics' technologies
    - provided access to advice, expertise, tools and resources
    - provided access to data and bioinformatics tools
    - provided easier access to 'genomics' resources that were developed elsewhere (e.g. through stock centres)
    - provided opportunities for training in 'genomics' for postdoctoral researchers and postgraduate students
    - provided centralised services that enabled smaller laboratories to compete with larger institutions
    - enabled grantholders to develop their research programme in new directions
    - enabled grantholders to win further grant funding
    - underpinned further research funded by BBSRC and other funding agencies
    - stimulated collaborations with UK and overseas academics
    - supported a variety of workshops
    - helped establish strong research communities
    - raised the international profile of UK bioscience research
    - acted as a model for other UK and international funding programmes

145. The reach of each IGF consortium was largely limited to the immediate research communities they served. Relatively few direct benefits were reported from researchers who worked with organisms outside the remits of the IGF consortia. There were indirect benefits which arose from the IGF initiative, but these were hard to separate from the effects of a global movement towards 'genomics' over the evaluation period. For example, it is likely that the IGF initiative encouraged researchers to seek responsive mode support to develop 'genomics' tools and resources in their own organisms of interest.

146. Four grantholders (6%) felt forced to change research direction as a result of the IGF initiative. They adjusted their own research to take advantages of the resources and services provided (as well as those developed through other funding programmes). Three grantholders commented on the positive aspects of these changes; however, one researcher noted that it became more difficult to obtain support for research using organisms outside the remit of the IGF initiative, even if they may have been more suitable for the proposed research. The Panel sympathised with this view, but noted that with limited resources, it was appropriate for BBSRC to focus its initial investments in 'genomics' research on a limited number of species.

147. Grantholders were generally very positive about BBSRC's support for 'genomics' research over the evaluation period. There was recognition that investment in centralised facilities, resources and services was necessary for 'genomics' research,

and that without appropriate provision, the UK would not have remained internationally competitive. Although directed initiatives are less popular than responsive mode funding among the research community, there was a consensus that the IGF initiative was an important and worthwhile investment: its primary focus was the development of enabling resources and services for the wider community. There was also recognition of the very important role of resources developed outside the initiative, particularly within US funding programmes.

# Conclusions

# 9. Conclusions

148. The introduction of ‘genomics’ technologies and their subsequent adoption by researchers was an exciting period in the recent history of the biological sciences. A suite of new experimental approaches became available, including genome sequencing, transcriptomics, proteomics, metabolomics and functional genomics. The IGF initiative was established at this early stage of ‘genomics’ to provide access to ‘genomics’ technologies for key BBSRC research communities. It complemented other UK and international ‘genomics’ funding programmes that were also developing community resources, and contributed to the greatly improved accessibility of ‘genomics’ technologies. The investment in the IGF initiative was followed by activities in responsive mode, where researchers were able to use ‘genomics’ technologies and approaches in their own investigator-driven research.

149. BBSRC’s strategy for building ‘genomics’ capacity in the UK bioscience community was effective. The IGF initiative built the initial capacity, developing high-quality ‘genomics’ tools, resources, facilities and datasets, providing good quality training in ‘genomics’ techniques, and strengthening research communities. The initiative enabled large sections of the BBSRC research community to incorporate ‘genomics’ technologies and approaches into their own research programmes, and it underpinned future research activities within responsive mode. The initiative also helped to ensure that the UK retained its leading position in bioscience, and was an example of where planning and concerted action in science did immense good.

150. Responsive mode grantholders used the ‘genomics’ tools and resources developed by the IGF initiative and other funding programmes to conduct high-quality research. They used ‘genomics’ approaches to address interesting and relevant biological questions, and make exciting discoveries. Responsive mode allowed for a broader range of research activities to be supported, and provided greater coverage of the BBSRC remit. In particular, responsive mode provided greater scope for researchers to develop ‘genomics’ resources for their own organisms of interest, and allowed the gaps in the coverage of the IGF initiative to be addressed.

151. The objective of the IGF initiative was to provide ‘genomics’ tools and resources for the wider community. As such, there were limited opportunities to deliver economic and societal impacts directly from the research. These impacts were expected to arise from the other research activities that the initiative underpinned. Responsive mode provided greater scope for making exciting discoveries which could contribute to the wider public good. Through responsive mode, researchers were able to pursue their own research directions and be more entrepreneurial, engaging with industry and other stakeholders, developing intellectual property and spin-out companies, and work towards the delivery of economic and societal impacts from their research. With each subsequent tranche of funding, researchers have become more familiar with increasingly advanced ‘genomics’ technologies, and as the research becomes more adventurous and sophisticated there will be increasing opportunities to deliver impact. BBSRC responsive mode has itself underpinned further research from other funding agencies who are supporting more translational research.

152. Although BBSRC’s support for ‘genomics’ research over the evaluation period was good, there were some areas that could have been improved. Most notably, the strategy for building capacity in ‘genomics’ research did not include postgraduate training as a formal objective, either explicitly in the IGF initiative or more generally through responsive mode. This was a weakness, which delayed progress towards

ensuring the BBSRC research community had access to the skilled staff required to conduct high-quality ‘genomics’ research. In addition, there was insufficient emphasis on the long-term maintenance of ‘genomics’ resources and the archiving of datasets developed by the research and, as a result, there was a risk that some resources could be lost.

153. Overall, BBSRC’s investment in ‘genomics’ research over the evaluation period was effective and produced lasting benefits for UK bioscience. It contributed to the high international standing of UK bioscience research, and positioned the UK to take advantage of subsequent developments such as those of systems biology. In addition, it helped to maintain a strong bioscience community, ensuring that the UK is able to address emerging global challenges.

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