RELU PROJECT END OF AWARD REPORT FORM

REFERENCE NUMBER
RES-224-25-0048

TITLE
Biological Alternatives to Chemical Pesticide Inputs in the Food Chain: An Assessment of Sustainability

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UK farmers and growers face the challenge of using more environmentally acceptable methods of crop protection while maintaining food quality, productivity and profitability. There are good opportunities to reduce chemical inputs using Integrated Pest Management (IPM) based on biological control agents such as naturally occurring fungi, bacteria, viruses or nematodes. The project focused particularly on microbial bio-insecticides, based on entomopathogens, for the control of insect pests which form part of a group of microbial biopesticides. They are applied in much the same way as chemical pesticides, but they offer a number of advantages such as low impact on non target organisms, compatibility with other natural enemies and limited toxic residue.

There has been a poor uptake of microbial pesticides in the UK. Relatively few products have been successfully registered and made available. This project focused on regulatory barriers to wider adoption. The regulatory system in the UK was developed in accordance with a chemical pesticides model which did not facilitate the registration of biopesticides.

The regulatory agency, the Pesticides Safety Directorate (PSD), introduced a Pilot Project to facilitate the registration of biopesticides in 2003 and converted this into a Biopesticides Scheme in 2006 offering features such as pre-submission meetings, reduced registration fees and a Biopesticides Champion within PSD. The project was able to study this process of regulatory innovation and work with PSD to provide training to facilitate the achievement of their objectives. It also enabled the development of a model specifying the conditions under which regulatory innovation was likely to occur.

The EU dimension of the system of regulation has been undergoing a process of change. The revision of the relevant directive, EC 91/414, was still under discussion when the project finished. However, the absence of a functioning system of mutual recognition between member states means that there is no effective internal market comparable with that of the USA which has had a much higher rate of biopesticide registration and adoption. This makes it difficult for the SMEs which are the typical developers and producers of biopesticides to secure economies of scale.

Major supermarket chains consider that they are under pressure from consumers to minimise pesticide residues. Consumer concerns about residues could undermine the achievement of the ‘five a day’ target in relation to the consumption of fruits and vegetables. Retailers stated in interviews that some of them sought to cultivate a greener image than competitors as part of a marketing strategy. This leads them to prohibit or control the use of pesticides that have been approved by the regulatory system. This could undermine confidence in the system, but it also means that growers are faced with
differing demands from different retailers that go beyond the regulations and add considerably to management complexity on farm. Retailers are also with one or two exceptions reluctant to take a proactive role in recommending the wider use of biopesticides. In academic terms, outputs from the project will explore the wider implications of this system of private retail governance.

A cross-national comparative element was introduced into the analysis by comparison with regulatory arrangements in Denmark, the Netherlands and the United States. The pesticides tax in Denmark was not considered to offer a way forward for the promotion of biopesticides. The Genoeg scheme in the Netherlands provides assistance with registration costs of new products. In the USA, the Environmental Protection Agency has a well resourced Biopesticides Division with a clear mission to facilitate biopesticide registration. This is helped by its links with the IR-4 programme. One lesson from these arrangements is that there may be scope for limited interventions to assist the development and registration of products.

Relatively little is still understood about the underlying ecology of bio-insecticides. However, research in Canada showed that two soil dwelling entomopathogenic fungi were adapted to local environmental conditions. This was a significant finding because it challenged a paradigm in insect pathology that the host insect is the predominant influence on population genetics. Local adaptation would have profound implications for the ability of natural entomopathogens communities to compete with bio-insecticide genotypes, and hence determine the efficacy and sustainability of bio-insecticide applications. The work undertaken in the project showed the existence of local adaptation in that particular strains represent an adaptation to both latitude and habitat such as woodland, ploughed field, permanent grassland etc. The results indicate that habitat type is likely to influence the environmental fate and behaviour of entomopathogenic fungal strains released as biocontrol agents. It would make sense to develop control agents for a particular habitat type using fungal strains from a genetic group adapted to the same habitat. Ecological niche theory suggests that such strains are likely to persist for longer (thereby giving more effective pest control) and there should be less of risk of the strain establishing in a heterologous habitat and causing unintended effects on nontarget organisms.

The project was characterised by effective engagement with a range of stakeholders. This was exemplified by two highly successful one day conferences organised by the project which attracted over one hundred participants to the first and seventy to the second from a range of stakeholders from growers through biopesticide manufacturers to regulators. Among the paper presenters at the conferences were an American biopesticides manufacturer, an environmental group, Marks and Spencers and the PSD.

The project team submitted a response to the draft National Pesticides Strategy and also took part in the informal and formal consultations run by Defra on the future of PSD. At a European level, the project was represented on the steering group of the European Commission policy action, REBECA (Regulation of Environmental Biological Control Agents). Project members took an active role in various workshops and played a key role in shaping the final report with Professor Grant serving as a member of the round table at the plenary session of the final conference in Brussels. The work undertaken in the project is consistent with Defra’s Science and Innovation Strategy objective to develop alternative plant protection technologies to reduce reliance on conventional pesticides.
Research report

Background

UK farmers and growers are facing a considerable challenge to adopt more environmentally acceptable methods of crop production and protection while maintaining food quality, productivity and profitability. The availability of such forms of plant protection is affected by both the development of resistance to existing products and legislative action. There is a major review programme in place under Directive 91/414/EEC which is designed to ensure that all the active substances that were on the EC market before its introduction meet modern standards. Approaching 1,000 substances are scheduled for review and about half of these have already been withdrawn, largely for commercial reasons. These are not being replaced at a comparable rate and for several major diseases, control rests on one group of actives which may already be encountering resistance. There are particular problems for minor crops, especially horticultural crops, where the size of the UK market is unlikely to attract the registration or production of new products.

Consumers continue to be concerned about the issue of pesticide residues. This could deter them from meeting the ‘five a day’ target for the consumption of fruit and vegetables. It should be noted that the emphasis in this project is also on the role of biopesticides in contributing to a more sustainable food chain. Other issues relating to the use of pesticides include worker exposure, bystander exposure and groundwater contamination.

There are good opportunities to reduce chemical inputs and provide alternatives using Integrated Pest Management (IPM) based on biological control agents. In particular, microbial control agents, based on naturally occurring fungi, bacteria, viruses or nematodes, can offer realistic alternatives to chemical pesticides when used as part of an IPM strategy. This project focused particularly on microbial bio-insecticides, also known as microbial control agents (MCAs), based on entomopathogens, for the control of insect pests. These and other microbial agents are known collectively as microbial pesticides and their use accords with Defra’s Science and Innovation Strategy for 2003-6 to develop alternative plant protection technologies to reduce reliance on conventional pesticides.

Despite their perceived advantages, there has been a poor uptake of microbial pesticides in the UK. The focus in this project was on shortcomings in the regulatory system. The overarching theoretical framework was derived from Moran’s understanding of the regulatory state as an incomplete from of modernisation. In terms of middle level theory, the focus was on theories of regulatory innovation and in particular an exploration of the conditions under which regulatory innovation can successfully occur. The safety and efficacy of fungal, bacterial and viral pesticides are regulated in the UK by the Pesticides Safety Directorate (PSD). The regulatory system was originally developed to register chemical pesticides and aspects of this emphasis acted as barriers to biopesticides commercialisation.

An alternative hypothesis is that what is being observed is market failure in the sense that insufficient returns can be generated from the market to justify commercialisation of the products. Biopesticides are typically developed by SMEs, often start ups that have to find funding to see them through the development and registration of a product.
Undoubtedly there are some products that would never be viable even if there were zero registration costs. However, the regulatory system itself has an impact on market size in terms of the failure to establish a working system of mutual recognition and hence an internal market within the European Union (EU). This makes it difficult to secure economies of scale and helps to explain the lower registration rate of biopesticides in the EU compared with the USA.

The environmental sustainability of deploying biopesticides in agricultural systems is unclear, and there is little understanding of the ecology of micro-organisms, even though they are naturally widespread in agroecosystems. Potentially, there could be unintended effects, for example, on the diversity and function of other natural enemies (including other strains of the MCA naturally resident in the area), or on sub-specific groupings of the target host species that are associated with non-crop plants. Most MCAs are used according to an ‘augmentation’ strategy in which the control agent is applied as a commercial product. Pest control is brought about by individuals of the released agent, but there may also be additional control due to the action of its progeny. Because the effects of these agents are largely dose dependent, any negative effects on non-target species should last for only as long as the agent persists. Anecdotal experience with agents such as entomopathogenic fungi used for augmentation biological control would appear to back this up. However, as we discuss in the ‘future research’ section, this is not to say that evaluation of new products is not required. In particular, if MCAs become used more widely, then the amount of environmental perturbation might increase.

**Objectives**

The overall objective of the project was to improve understanding of the environmental and regulatory sustainability of biopesticide development and utilisation, using a fungus-based microbial bio-insecticide as a model system.

**Objective 1: To assess the limitations of a chemical pesticide driven regulatory model in terms of encouraging the wider use of environmentally-friendly biological methods of pest control and to consider the obstacles to regulatory innovation within a broader model of the regulatory state.**

*Identify principal actors in the pesticide regulation system and their inter-relationships*

This was successfully undertaken and good relationships were achieved with a range of governmental and non-governmental stakeholders. The detailed results secured are discussed under ‘results’.

*Specify the inadequacies of the present system from a bio-insecticides perspective*

The period of the research saw innovations by PSD which addressed many of the inadequacies in the existing system from a bio-insecticides perspective in terms of their registration being considered within a chemically driven model. The extent to which these innovations were successful are discussed in the ‘results’ section of the report.

*Outline the main design principles of a revised system*
This objective is met through out RELU principles document which is one of the two principal outputs submitted in association with the report. This proceeds through an analysis of five underlying principles and ten operating principles. The contents of this report have been extensively discussed with stakeholders and it provided the basis for the four page summary document of findings produced in conjunction with the RELU team in Newcastle.

**Objective 2: To provide new information on the persistence of wild and inundatively-released genotypes of entomopathogenic microrganisms applied as microbial bio-insecticides.**

*Component objectives*

*Investigate the effect of habitat type on the biodiversity of entomopathogenic fungi in the agroecosystem and look for evidence of local adaptation of indigenous populations.*

*How was this Objective met?*

In this Objective, experiments were done to investigate whether natural populations of entomopathogenic fungi exhibited a spatial pattern in the distribution of biodiversity. Spatial patterns were investigated at two taxonomic levels (a) within a species, and (b) within assemblages of entomopathogenic fungi from different locations.

*Determine the prevailing life history strategy of M. flavoviride var pemphigum and other fungal genotypes through investigation of econutritional behaviour. Characterise the fate of M. flavoviride var pemphigum when applied as an inundative bio-insecticide against diverse genotypes of P. bursarius.*

Investigations early in Objective 1 showed that habitat type had a significant effect on the pattern of biodiversity of entomopathogenic fungi. Because this could have important implications for the regulation and use of these agents in biological control, it was decided to concentrate on this aspect of the project.

**Objective 3: To assess the contribution, in terms of benefits as well as costs, of biopesticides to sustainability and whether their uptake will be constrained by social factors, including the composition of existing decision-making networks**

*Specify the benefits and costs of bio-pesticides in terms of contributing to a sustainable and competitive agricultural industry*

This objective was pursued by convening a workshop with a range of experts from the natural and social scientists, including an economist and sociologist, to assess the costs and benefits of biopesticides in the light of the findings from the project. The detailed results are presented in the ‘results’ section of the report.

*Using the insights of policy network theory and interviews with key actors, identify the change agents and processes that would create a momentum that would sustain regulatory innovation*

This forms the subject of the paper by Justin Greaves which is submitted as one of the key two academic outputs from the project. This suggests that a combination of exogenous and endogenous factors was necessary to bring about the regulatory innovation. The exogenous stimulus was provided by an industrial executive seconded
to the Better Regulation Executive, then located within the Cabinet Office, who pursued the issue of the low level of biopesticide registrations. This challenge was then effectively responded to within the Approvals Branch of PSD, both by the leadership of the Branch and by a team of middle level managers acquiring relevant expertise and implementing solutions.

A momentum for sustained innovation has been achieved. However, this could be disrupted by changes in the organisational arrangements for PSD that led to any change in emphasis in its objectives or to significant losses of personnel associated with the Biopesticides programme. Although ensuring the safety of approved products will always be a core mission for PSD, it also needs to continue to have the capacity to take broader sustainability objectives into account in its work.

*The results of this objective will be communicated with stakeholders in a workshop*

Two one day conferences were held (see below), but the formal results of the cost benefit analysis were communicated in the second workshop. The results were also incorporated into a paper presented by a speaker at the final REBECA workshop in Brussels.

**Objective 4: To compare and evaluate the supply chain (retail) driven, private governance model of pesticide reduction in the UK with its legislatively driven counterpart in Denmark.**

The research showed that retailers were imposing requirements on growers that went beyond those required by the state regulatory system. Although they prohibited some approved chemical pesticides, this was not necessarily helpful to the wider adoption of biopesticides. It was found that the regulatory system in Denmark was driven by concerns about groundwater pollution and did not facilitate wider biopesticide use. Hence, the comparative perspective was broadened to include Netherlands and the United States. These points are discussed more fully under ‘results’.

**Methods**

The principal method used in the political science aspect of the project took the form of semi-structured interviews with a range of relevant actors:

1. Staff of the PSD
2. Manufacturers and developers of biopesticide products
3. Growers (including site visits)
4. Retailers
5. National Farmers’ Union
6. IBMA
7. Environmental organisations
8. Consultants
9. Actors at the EU level
10. Environmental Protection Agency, USA
11. Genoeg scheme, Netherlands
12. Danish regulators
These formal interviews were supplemented by informal discussions at a number of events including REBECA workshops, the project’s own workshops, IBMA events, conferences of learned societies and training provision at PSD.

Use was also made of observational techniques. Pre-submission meetings with potential registrants of products were observed at the PSD with their consent and that of the applicants. A closed meeting of the Advisory Committee on Pesticides (ACP) was observed and an open meeting attended.

Considerable use was also made of a range of documentary sources including PSD and government reports, reports of the European Parliament and documentation issued by regulatory agencies outside the UK, including state level agencies within the USA.

Ecological survey of frequency of occurrence of soil based entomopathogenic fungi in woodlands at different geographical locations

Soil samples were collected from nine woodlands from 8 English counties. Samples were collected at intervals of approximately 5 m randomly throughout each wood, with approximately 200 samples collected per location. Fungi were isolated from samples by baiting with larvae of the wax moth, *Galleria mellonella* (Bedding and Akehurst, 1975). Fungal material was placed into cryo-storage. Fungi were identified to species level using morphological criteria of Brady (1979) and Samson *et al.* (1988).

Phylogenetic analysis of isolates of the entomopathogenic fungus Beauveria bassiana sensu lato from contrasting habitats (woodlands vs grassland habitats) collected from different locations across the UK

One hundred and seventeen isolates of *B. bassiana* sensu lato were chosen at random from the Warwick collection of entomopathogenic fungal cultures. Isolates originated from either woodlands (nine locations) or grassland (11 locations). Nucleotide sequence information was generated for the following loci: elongation factor 1α; 28S rDNA group I intron; beta tubulin, DNAlyase, and beta locus. Allele lengths of *B. bassiana* microsatellite loci (Rehner & Buckley, 2003) were also obtained. DNA extraction, primer design, PCR and sequencing were done using standard methods. Following visual inspection of nucleotide sequence data, multiple sequence alignments were done using pruned sequences.

Phylogenetic analysis of *B. bassiana* sensu lato isolates collected from different habitat types within the same geographic location.

Over 1000 soil samples were collected from four adjoining fields plus hedgerow at the Warwick experimental farm. The sampled fields comprised 10 ha of meadow, 7 ha of arable (barley), 12 ha under Countryside Stewardship (wild flower mix held under CS for 3 years prior to sampling). Samples from fields were obtained in a grid pattern whereas samples from hedgerow were obtained in a linear array. Isolates of entomopathogenic fungi were obtained from soil samples using the *Galleria* baiting technique as described previously. A total of 99 isolates of *B. bassiana sensu lato* were used in phylogenetic analysis as described above.

Interdisciplinarity
The initial procedure adopted to gain familiarity with each other’s disciplines was for team members from the other discipline to read and present articles from the discipline with which they were not familiar at team meetings. This procedure worked very well and allowed the development of familiarity with the terminology and approaches of the contrasting discipline.

The challenge then was to ensure that each discipline was affected in a positive way by the other discipline. In the case of the political scientists, the technical understanding of the biological scientists was essential to the interpretation of the regulatory frameworks studied. It was also found that the natural scientists possessed considerable information and understanding about decision-making processes and policy networks which had never been utilised systematically and which could be placed within the theoretical frameworks of political science. For their part, the biological scientists had been used to a solutions oriented, applied approach to problems of plant pathology. They were encouraged to pursue a more deductive theoretically driven approach by the political scientists.

The project took a lead within RELU in organising events designed to stimulate thinking about the challenges of interdisciplinarity. The project group obtained funding from the British Academy to stage a well attended workshop at their premises in London in May 2006 on interdisciplinarity which included an opening paper by David Chandler and Wyn Grant on ‘Working Across Disciplines: Challenges for the Natural and Social Sciences’. This was followed up by a British Academy sponsored panel convened by Wyn Grant at the Festival of Science in York in September 2007 which, as well as a paper by David Chandler and Wyn Grant, included papers on the interdisciplinary aspects of four other RELU projects.

The contribution towards interdisciplinary work has been in terms of proposing practical and effective methods of working across disciplines and the consideration of similar and divergent methodological challenges. It is hoped to develop this work through a publication written in conjunction with other RELU teams.

Results

Shortcomings in the policy network

What became evident was that this was a relatively immature policy network in terms of the frequency of interaction between various stakeholders. There had been a successful attempt by the PSD to reach out to and interact with the main trade association for manufacturers of biopesticides, the International Biocontrol Manufacturers’ Association (IBMA). However, the IBMA, although undergoing continuous organisational development through the project, was hampered by a lack of resources and by the fact that its technical knowledge was not always matched by a comparable level of political sophistication. It also did not organise all potential registrants of biopesticides which was a challenge for PSD in their outreach efforts directed at the industry.

What was also evident was a lack of developed interaction between some key actors in the system. Interaction between PSD and retailers was somewhat patchy, to some extent reflecting different objectives. There was also a lack of engagement by environmental groups in the biopesticides debate, reflecting indifference rather than hostility.
Consultants were potentially important intermediaries in the policy network and were active in IBMA. However, there was a concern that in certain instances they could convey the impression to some clients that access to the regulatory system was more difficult than was in fact the case.

Regulatory innovations at a domestic level

The system was undergoing development during the period of the research project and this provided a valuable opportunity to observe regulatory innovation in action. In 2003 the PSD launched a Pilot Project to facilitate the registration of biopesticides and this was developed into a Biopesticides Scheme in 2006. Among the key features of the Scheme were the active use of pre-submission meetings, substantially reduced registration fees and the appointment of a Biopesticides Champion as a point of contact within PSD.

The introduction of the Scheme provided an opportunity for PSD to develop their understanding of these products and their distinctive characteristics. PSD understandably developed expertise in approving synthetic pesticides and these continue to represent the bulk of the business of an organisation that operates on a cost recovery basis. Nevertheless, PSD has been willing to devote resources and develop new expertise to improve the service that it offers to those seeking approval for biological products, although the learning curve has been a steep one at times. For example, PSD staff have had to familiarise themselves with the fact that different questions have to be asked about biological products, and that questions that may be important for synthetics are not necessarily relevant for biologicals. There has also been a need to develop an understanding with applicants of when and how published data might be used to answer certain types of questions.

One has thus seen the replacement of a chemically driven regulatory model by a modified model that is more adapted to the specific needs of biological control agents, leading to a partial resolution of ‘regulatory failure’ problems. This has produced a modest increase in the number of biological products being registered with others in the pipeline. In seeking to explain why the number of registrations has not been higher, a number of explanations are relevant:

i) Despite the best efforts of PSD, the fragmented and SME dominated nature of the industry makes it difficult to reach all potential registrants who often seek assistance later in the registration process than is desirable.

ii) Some products may simply not be viable, even given reduced registration costs.

iii) Some products may be marketed outside the registration as plant strengtheners etc.

Incomplete reforms at the EU level

The revision of the Directive 91/414/EEC and the consideration of the Commission’s Thematic Strategy on Pesticides were being undertaken while the project was in progress, but were not completed. The discussion on these matters was carefully monitored and this work will continue after the project has finished informing the book to be produced from the project.
It was recognised that the mutual recognition was not working and the Commission attempted to overcome this by proposing a system of three eco zones within which mutual recognition would take place. This proposal met a number of objections and it was defeated at the first reading stage in the European Parliament. The final outcome of the co-decision process will not be known until 2008. However, the research undertaken in the project suggests that the absence of a Europe wide market for biopesticides is a significant obstacle to their wider commercial availability.

Costs and benefits of biopesticides

The work undertaken in this area showed that benefits and costs differ according to the perspective of six different stakeholders: developers; regulators; users/growers; retailers; consumers and opinion formers. Eight distinct benefits were identified as relating to all six groupings, twenty-five costs and eight items where there were a mixture of costs and benefits between the different groupings. The latter are particularly challenging in terms of policy recommendations as they represent areas where the perceptions and/or weightings of stakeholders may conflict.

It is interesting that the balance of identified costs and measures varies substantially across the six groupings with the most negative balance found for developers (-14) and users/growers (-9). The balance for retailers is moderately negative (-6), evenly balanced for regulators (-1), but positive for consumers (+2) and opinion formers (+7). Thus, those who bear the private costs of development and application seem to have the most unfavourable balance of costs and benefits. These include key actors involved in the maintenance of a competitive and sustainable agricultural industry.

One of the strongest benefits of biopesticides are that they offer a more sustainable solution than synthetic alternatives, or more specifically that they allow chemical pesticides to be deployed where and when they are most needed and most appropriate so that a precious resource is not squandered. Hence as chemical pesticides are withdrawn because of resistance problems or because they are no longer commercially viable, a space is created for biological solutions to occupy. Indeed, it is often not commercially viable to develop chemicals for niche markets, posing a challenge for minor crops which include the salad crops and other vegetables that make a substantial contribution to health policy objectives.

One of the clear benefits of biopesticides is that they can be combined with other solutions. They can complement other forms of biological control, e.g., conservation measures such as beetle banks. They can allow the use of other forms of control with low efficacy, e.g., where there is partial resistance to existing products. They are also relatively cheap to develop and need to be redeveloped less frequently, saving expenditure on research and development. Herbicides remove bird food but because biopesticides are less efficacious, more bird food is available and bird populations (a key indicator of environmental stress) should increase.

Many of the issues relating to costs are grouped around the question of efficacy. In general terms, biopesticides are not as effective as chemicals. With a chemical product, provided one knows its composition it is easy to predict what it will do, whereas with a biological product one has less confidence about how it fits into the ecosystem. Biopesticides may not work immediately as the ecological background must change. Compatibility with synthetic pesticides varies. Shelf life is often shorter. Speed of kill may not be as fast, although in part this is a consequence of thinking within a chemical paradigm and can be got round by appropriate labelling (which is one of the functions of the regulatory system).
There are differences in efficacy between performance in protected and field crops, although it should be remembered that biopesticides have been used successfully with broad acre crops. However, it is easier to monitor a crop in a greenhouse and to demonstrate to crop consultants that it works.

Farmers have to decide to take more risks with biopesticides, but the incentives may be absent as most of the benefits are external to farmers. They have to be used in relatively complex knowledge intensive management systems which act as a disincentive. More knowledge is required for their use, but there is a shortage of relevant technical skills in horticulture, reflecting low wages.

The research suggested that benefits of biopesticides outweigh costs, but a number of challenges have to met, including negative public perceptions of the term ‘biopesticides’. It might be possible to provide an ethical marque for products on the lines of ‘Freedom Foods’. To achieve this, NGO involvement would be necessary and better links between different parts of a fragmented policy network.

New chemical formulations could be used to solve biopesticide storage and efficacy issues and might lead to greater interest from large companies. Biopesticides need to be fitted into current stewardship schemes to provide incentives for their use. This would also integrate crop and environmental management in a way that promoted sustainability.

Of fundamental importance is the distinction between private and public benefits and costs and how these are shared out among the various actors in the production and food chain. In terms of liability the regulatory process is about sharing that out between the manufacturer, regulator, government and society. The externality impacts confirm that regulation is important. Food is not just a private individual good, although it may be perceived as such and does not have all the characteristics of a public good. It is, however, easier in principle to charge the consumer for food safety as part of a ‘bundled’ good, but a free rider problem arises in charging for the collective good of environmental protection.

It is evident that, given the disappearance of many actives, biopesticides have a potentially important contribution to make to a competitive agriculture industry. They do not leave toxic residues and rarely have significant environmental impacts, thus having the potential to provide more sustainable benefits. They have the potential to increase consumer confidence in fruit and vegetable products whilst moving away from a polarised and over simplified choice between conventional and organic modes of production.

Theoretical understandings of regulatory innovation

How and why does regulatory innovation occur? Black (2005) divides up the explanations and theories into five ‘worlds’: the worlds of the individual, the organization, the state, the global polity and the innovation. In terms of Black’s five worlds, key individuals have been vital in driving the process forward, both within the Cabinet Office and PSD. Similarly, organisational characteristics have played a key role (eg: the vertical distribution of work, a desire for empirical knowledge, interpersonal connections etc). In relation to ‘the state world’, the intervention of the Cabinet Office intervention along with the impact of institutions should not be understated. The ‘global world’ is of less significance but PSD operate within OECD guidelines, have engaged with REBECA, and the review of 91/144 could be significant. In terms of the ‘world of the innovation’, biopesticides fit into their surrounding environment, not least in terms of issues surrounding sustainability, pesticide resistance and the limited number of products.
Based on our research into PSD, we propose a framework or model whereby regulatory innovation in a regulatory agency, all things being equal, will be promoted by:

- Exogenous pressure from central government.
- Key individuals within the organisation being prepared to drive through change.
- Selecting the right individuals to work on innovative projects.
- ‘Political’ as opposed to ‘technical’ regulators (but with a degree of independence from government).
- A vertical distribution of work.
- Regulators keen to learn and develop their expertise (in particular scientific regulators).
- Small organisations (with a clearly defined purpose).
- Commercial or financial pressures.

In terms of the regulatory state model, the priority given to regulation sets up expectations of innovation and responsiveness to societal demands which can be hard to meet in practice. In relation to regulatory innovation frameworks, there is a fundamental tension between expectations that regulators will be consistent, predictable and impartial and yet also innovative. The consequences of making a mistake are serious, especially where public safety/environmental protection is involved, but regulators also have to respond to changing demands in society. Regulatory innovation is also important if regulators are to retain the trust of politicians and stakeholders. It is evident that the notion of regulators being cut off from society and not being prepared to engage is, at least in the case of PSD, not true. The activities of PSD also suggest that regulatory innovation is possible within a regulatory agency. It requires a government steer, appropriate contextual circumstances, and a positive response from the agency based upon the suitable individuals and the right organisational and institutional characteristics.

Role of retailers

Our interviews with retailers confirmed that in most cases they had arrangements that banned, or at least restricted the use, of approved chemical pesticides. In one case this involved a five-grade classification of pesticides with three variants of the amber grade. From the grower perspective, this meant that the range of plant protection products available to them was further restricted and also complicated by the fact that different retailers had different requirements. Retailers also carry out extensive testing of their own to detect residues, although tracing the source of any problems is difficult when suppliers are outside the UK.

From a retailer perspective, they saw themselves as responding to the expressed preferences of consumers to have as few residues as possible on products. Emphasising that their products were as free of pesticides as possible was seen as a commercial strategy in relation to competitors. Retailers felt unable to promote specific biological solutions as they could not endorse particular products. They were also constrained by the lack of any clear consumer image of biologicals or IPM.

From a regulatory perspective, although the private system of retailer governance is not a ‘regulatory’ system in the strict sense of the word, it does imply that products that have approved through a rigorous system are in some sense unsafe. The specific issue of
pesticides raises broader questions about the role of the retailer in the food chain which will be explored in publications arising from the project.

**Internationally comparative work**

An initial comparison was made with the system of pesticides regulation in Denmark. This was found to be strongly driven by concerns about pesticides in groundwater. Although the pesticides tax, which was applied at a lower rate to biopesticides, did release some resources for biopesticides research, it was not judged to be a superior model to the Voluntary Initiative in Britain.

A visit to the Environmental Protection Agency in the United States found that its Biopesticides Division was well resourced, had a clear identity and took a proactive stance. Its work was also assisted by the financial support made available through the IR-4 programme. These institutional arrangements contributed to a higher take up of biopesticides in the US compared with Europe.

A visit was made to the Netherlands for discussions with members of the Genoeg project that promotes the adoption of biopesticides. Its work has to be seen within the context of the importance of the protected crops industry in the Netherlands and specific Dutch environmental issues. Nevertheless, the experiences here and in the United States suggest that small sums of public money used for pump priming may assist the development of biopesticides.

**Effect of habitat type on the biodiversity of entomopathogenic fungi**

Contingency table analysis of data for fungal isolates obtained from the English woodland survey indicated a significant effect of location on the frequency of occurrence of entomopathogenic fungi in soils and a significant positive relationship (P < 0.05) between latitude and frequency of occurrence (the frequency of occurrence of entomopathogenic fungi increased moving further north). Phylogenetic trees of *B. bassiana sensu lato* collected from woodlands and grassland at different locations in England showed three well supported clades associated with habitat type. Comparison was made with Rehner & Buckley’s (2005) *Beauveria* phylogeny inferred from nuclear ITS and EF1α sequences using exemplar isolates from diverse geographic regions, habitats and hosts and which identified six well supported clades which did not correspond exactly with the accepted morphological species for the fungus. The three deep rooted clades identified in our project corresponded with Rehner and Buckley’s (2005) *Beauveria* clades A (= *B. bassiana*), B (= *B. brongniartii*) and C (= *B. c.f. bassiana*). Chi square analysis of the proportion of *Beauveria* isolates from either woodland or grassland in clades A – C showed a significant (P < 0.001) effect of habitat. Isolates originating from woodlands and grasslands were represented in all three *Beauveria* clades, but isolates from grassland were significantly over-represented in clade A, while isolates from woodlands were significantly over-represented in Clades B and C. Thus habitat type has a significant effect on the genetic structure of *Beauveria* communities in England. The influence of geographic distance on the relatedness of isolates was not clear and it is likely that evolutionary models will need to be applied in future work to determine the relative influences of habitat type and geographic location. It is not yet clear how the spatial (habitat) pattern of *Beauveria* diversity relates to the niche requirements of individual clades as host organism, rather than the external environment, is thought to be the major driver for patterns of diversity in micro-parasites. The spatial pattern observed in this
project could mirror the effect of habitat type on the biodiversity of insect hosts for the fungus. On the other hand, Beauveria clades A - C are considered to be generalists, and the fungus spends part of its lifecycle outside of the host in the form of conidia. Thus the fungus could exhibit a direct adaptation to particular habitats.

The same relationship between habitat type and clade structure was found in the survey of B. bassiana sensu lato isolates from soils collected from different habitats in the network of fields on the Warwick farm. The B. bassiana sensu lato community from this location comprised the same three deep rooted clades A – C as seen previously and there was a significant (P< 0.001) effect of habitat on the proportion of isolates from hedge vs. field in different clades. Clade A contained significantly more isolates from field habitats than expected while Clade C contained significantly more isolates from the hedgerow (and hedgerow would appear to be providing the same niche as woodland). Thus the population structure of Beauveria clearly showed an effect of habitat type at the within-farm scale. A significant habitat preference (chi square, P < 0.001) was also evident from data on the frequency of occurrence of the different morphological species of entomopathogenic fungi from the soil samples collected from the Warwick field system. Five morphological species were obtained: B. bassiana, Metarhizium anisopliae, Paecilomyces fumosoroseus, Paecilomyces farinosus, and Lecanicillium muscarium. Beauveria bassiana was the most common fungus identified and occurred most frequently in the permanent grassland habitat % and least frequently in the arable field. There was also an effect of habitat type on the frequency of occurrence of P. fumosoroseus which occurred more frequently in hedgerow soil than the open field habitats.

The results indicate that habitat type is likely to influence the environmental fate and behaviour of entomopathogenic fungal strains released as biocontrol agents. It would make sense to develop control agents for a particular habitat type using fungal strains from a clade adapted to the same habitat. Ecological niche theory suggests that such strains are likely to persist for longer (thereby giving more effective pest control) and there should be less of risk of the strain establishing in a heterologous habitat and causing unintended effects on nontarget organisms.

Capacity-Building and Training

The political science post-doctoral research fellow on the project, Dr Justin Greaves, was exposed to the interdisciplinary experience of working in the team and RELU and other conferences that had a substantial interdisciplinary component. He was thus able to develop his interdisciplinary experience and skills, enabling him to secure a post on a RELU 3 project. The biological scientist on the project, Gillian Prince, developed skills in fungal molecular ecology. She had no exposure to social science in previous work and her participation in the working of the interdisciplinary team enabled her to observe and participate in the political science research process.

Outputs and Data

The project used a variety of forms of dissemination, including an I-cast video made available on YouTube. The project produced the first four page summary document of findings within the RELU programme and a longer version of this document was produced for dissemination to stakeholders. A contract has been signed for a book based on the results of the project with CABI Books.
Knowledge Transfer, User Engagement and Impacts

There was extensive interaction throughout the project with a range of stakeholders, but particularly with the PSD. Use was made of the Work Shadowing and Visiting Fellowships schemes of RELU to provide training for PSD staff. This took the form of a number of lectures at their offices, both on the underlying science related to biological control agents and the general issues faced in regulation. A visit was also organised to Warwick HRI which included a visit to an ornamental producer and a workshop to exchange views on both regulatory issues and the relevant science. In the statements they produced for the RELU conference in London in November 2007, PSD staff attested to the value of interaction with an external research programme for the work they were developing in relation to biological control agents.

The original project proposal provided for one workshop to disseminate results to users, but the level of interest in the work being undertaken in the project made it possible to hold two such very well attended events. The first was held at the Royal Agricultural Society of England at Stoneleigh Park in October 2006 and was attended by over 100 participants from a wide cross-section of the industry from growers to retailers. The second was held at Warwick HRI in October 2007 and attracted over 70 participants. At the events, in addition to papers from the project, there were presentations from manufacturers, including one from the United States, consultants, regulators, retailers and an environmental organisation. The attendance and range of participants at these events demonstrated that the project was of real practical relevance to stakeholders. The project was selected as an example of effective engagement with stakeholders in the Defra Science Advisory Council Social Science Sub-Group Report on Social Research in Defra.

The research also made a submission to the review of the National Strategy on Pesticides and contributed responses to the informal and formal reviews conducted by Defra of the future of PSD. Wyn Grant participated in a stakeholders’ meeting as part of the second Defra review. Wyn Grant made two presentations about the project to the RELU Food Forum which brings together a wide range of stakeholders. A presentation on the project was given to Syngenta at their research station in Berkshire.

The project also took an active part in the European Commission REBECA (Regulation of Environmental Biological Control Agents) policy action through Wyn Grant’s membership of the Steering Group. Through a presentation at the REBECA conference at Salzau in 2007 and Wyn Grant’s contribution to the plenary Round Table at the final REBECA conference in Brussels in September 2007, outreach to a wider European audience was facilitated. Wyn Grant took a very active part in various working group meetings of REBECA, helping to draft the final report in a reform which would be useful to the European Commission.

Future Research Priorities

More understanding is required of how consumers perceive biopesticides with particular emphasis on giving them a generic name which would have less negative connotations. Consumers evidently have a clear understanding of ‘organic’, whether correct or complete or not, but there is little or no understanding of ‘biological control agents’ or IPM. Work therefore needs to be undertaken with consumers, through focus groups,
citizen juries etc. to explore their understanding of other sectors. This might be extended to cover the use of pesticides in the so-called ‘amateur’ market.

Accumulated experience by researchers and practitioners indicates that MCAs used in augmentation biological control can give effective pest control with minimal detectable negative impact on the environment. But there is a lack of meta-analyses in the scientific literature of the long term impact of these agents and it became apparent during this project that regulators and biopesticide manufacturers are not basing risk assessment of products on ecological theory, nor are they using theoretical approaches to make best use of the biological properties of MCAs. Although detectable risks of MCAs in use are thought to be low, lack of evidence of negative effects does not mean that new microbial products should be exempt from safety testing, since different species and strains of a microbial species can vary significantly in host range, pathogenicity and other biological characteristics which can potentially affect environmental safety. A priori, applications of control agents that are endemic to the area of release should not be expected to cause permanent disturbance. However, exactly which entities are classed as ‘endemic’ may be more complex than it seems at face value (Desprez-Loustau et al., 2007). For commercial reasons, proprietary MCAs may involve the use of non-endemic strains in the area of release which could have potential to impact on endemic strains or non-target organisms if they persist. Therefore providing fundamental data on diversity and biogeography of microbial natural enemies is a critical step in underpinning risk evaluation. This should enable regulators and others to respond better to future political developments based in part around potential conflicts of interest between stakeholders (for a discussion on the impacts of these tensions on the development of biological control agents, see Briese (2005)).