Global trends in ecological studies of GMOs

W.M. Lonsdale
CSIRO Entomology, GPO Box 1700, Canberra, Australian Capital Territory 2601, Australia

Summary The following themes appear to be emerging in the scientific literature on the ecology of genetically modified organisms (GMOs):

1. increasingly broad framing of risk studies to consider off-site, off-target, and ecosystem level effects;
2. disagreements over appropriate baselines for comparison of GMO impact;
3. non GMO introductions as model systems;
4. increasing emphasis on studying the effect of GMOs in a broader sustainability context; and
5. risk studies that take in a wider range of GMOs than the pest- or weed-protected crops currently being planted.

I discuss these trends and their implications for research in Australia.

Keywords Risk analysis, precautionary principle, biodiversity

INTRODUCTION

The survey that follows is an attempt to draw out the emerging trends and issues in the scientific literature on the ecology of genetically modified organisms (GMOs). The themes identified are probably not an exhaustive list but they seem to be real.

THEMES

Increasingly broad risk framing At first, risk assessment of GMOs (see Table 1) was envisaged to be moving as a linear progression from testing to predictability to commercialisation. As data accumulated, it was thought that commercialisation would become easier and easier. However, as time has gone on, GMO risk assessments have been framed increasingly broadly, particularly in Europe (Carr 2000). In consequence, regulatory hurdles seem to be getting higher with time.

Considerable debate has centred on the role of the Precautionary Principle (PP) in hindering innovation. There has been an unfortunate tendency in the biotechnology advocacy literature to distinguish between 'precaution' on the one hand and 'science-based regulation' on the other (Stirling 2001). There is no reason to assume that the two are mutually exclusive, but the PP is subtle and merits careful consideration.

In 1992, governments (Federal, States and Local Governments) in Australia agreed to follow the PP as part of a commitment to ecologically sustainable development. There are many formulations of the principle, but that adopted by these governments was:

> *Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by: (i) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and (ii) an assessment of risk-weighted consequences of various options.*

Other governments around the world have adopted the PP to a greater or lesser degree, and it is certainly a watchword for environmental groups who are critics of GMOs.

A further useful clarification of the PP and its implications for technology risk assessments has been proposed by Stirling (2001). He uses a two axis model to explore the relationships between risk, science and precaution. The two axes are (i) the degree to which an appraisal is scientific, and (ii) the breadth of perspective of the appraisal. For Stirling, the 'ban everything' approach (which is how the PP is caricatured) is high

Table 1. Some models for assessing the risks of GMOs.

Model	Source
NRC risk assessment model for genetically modified plants and micro-organisms	NRC 1989
Population dynamics model for assessing the risks of invasion for genetically engineered plants	Parker and Kareiva 1996
Cornell/ICET risk assessment schema for release of biotechnology products	Strauss 1991
GENHAZ – a system for critically evaluating hazards of genetically modified organisms	RCEP 1991

on the breadth axis, but very much towards the unscientific end of the science axis. In reality, according to Stirling, the PP is transparent, systematic, sceptical, and scientific, and involves broad framing of risk assessments (see Stirling 2001). In practice, a layered or tiered risk assessment that maintains conservative assumptions until additional data allow a higher level of assessment, embodies the precautionary principle (Fairbrother and Bennet, 1999, K. Hayes in press).

Baselines for comparison What is the baseline for comparison of the GM crop's impacts? The predominant view among regulators globally has been that the impacts of GM crops should be compared with the impacts of conventional (high impact) agriculture as the baseline. Thus, a Bt crop might be judged unlikely to cause more harm than a conventional crop sprayed with chemical pesticide. However, some countries such as Denmark and Austria believe that GM crops should offer an improvement over conventional agriculture, and Austria, in wishing to move towards organic agriculture, believes that this should be the baseline for comparison (see Carr 2000).

Non GMO introductions as model systems Williamson (1996) has argued that we can use non GMO introductions as model systems for understanding the risk profiles of GMOs. Broadly, of the thousands of organisms introduced to a new region, a tiny minority will become harmful, but this probability of harm varies with the organism, the region, and the mode of introduction. Impacts from introductions result from an interaction between the organism and its environment – the same organism may be harmful in one region but not in another.

This is also true of its beneficial effects – obviously, an insect resistant plant introduced where insect pests are rare will have no advantage over non-resistant plants. Small genetic changes can be critical in determining outcomes of introductions – it took several tries to get a rabbit population breeding in the wild in Australia, but, the right population being found, it became one of Australia's worst vertebrate pests (Williamson 1996).

Predictability of harm for biological introductions is low, for various reasons, among them:

- cascades in ecosystems – food webs, etc., which amplify or damp effects;
- scale effects are paramount in ecology – what is true in field plots at 1 ha is unlikely to be true at 10^4 sq km;
- lag phases before harm is caused – e.g. it may take 150 years for trees to become invasive (Kowarik 1995); and
- the base-rate effect – because technologies are not always taken up and used successfully, the rate at which introduced organisms become useful is also probably quite small. Because of the base-rate effect, the predictability of both harm and benefit is generally low (Smith *et al.* 1999).

All of these phenomena are reasonably well known and studied in the literature on biological invasions but are still emerging issues in the GMO risk literature, which perhaps has its origins more in a biosafety/human health tradition than it does in ecology.

Studying the crop in a broad sustainability context The impact of a crop on the environment may be both direct and indirect. The latter effects are particularly hard to predict, as they are consequent on imponderables such as changes to management regimes, uptake rates, farmer and market behaviour and so on. The decline in bird diversity in the United Kingdom in the past few decades has been blamed on the increasing intensification of agriculture, with the loss of weed diversity (mostly native species in the UK), and a consequent effect on bird populations. The potential for GM crop management to cause further decline of bird populations was the cause of much of the GM controversy in the UK. The recently published UK Farm-Scale Evaluations (FSE) were a large (£5m) thoroughly designed (see Firbank *et al.* 2003 and Perry *et al.* 2003) trial of impacts of GMO farming systems on biodiversity (DEFRA 2003). They involved three years of data collection, with 2002 being the final year of field experimentation. The experiment was set up to:

- test the hypothesis that the commercial *management* (i.e. not just the crop itself but all the practices involved in managing it) of GM herbicide tolerant (GMHT) crops does not affect farmland biodiversity compared with the management of the comparable non-GMHT crops; and
- estimate the magnitude of any differences that are found.

Maize, sugar beet, and winter and spring canola varieties were used in the trials though GMHT crops are not used commercially at present in the UK. The plantings were by farmers as licensees to the firms developing the crops. The trials involved:

- comparisons between GM and non GM;
- 25 farms per crop per year;
- representative, realistic farm conditions and scale; and
- minimal interference from experimenters.

The experimenters measured:

- aspects of crop management; and

- biodiversity assessments of soil seed bank, weeds, vegetation in the field boundary, slugs and snails, butterflies, bees, beetles, bugs and other insects.

Rigorous methodological studies (Perry *et al.* 2003) had previously established the required level of replication required to give the desired sensitivity. These had also shown that, even with the scale and number of replicates used here, studies of vertebrates would be unlikely to be sensitive enough to detect an effect of GM crops. Vertebrates however had to be included because of their high public profile, but were relegated to an ancillary study.

The results, when published in late 2003, were a fascinating demonstration of the way context determines the importance of an ecological data set. When the FSE showed that GMHT sugar beet and canola drove down native weed and invertebrate populations, the implications for policy were clear and the decision was made not to allow their commercial use. In Australia, by contrast, crop weeds are all exotic species, widely regarded as undesirable. Moreover the focus of our conservation efforts remains our wilderness areas and remnant vegetation. GMHT crops may perhaps be undesirable in terms of impacts on nutrient cycling or the potential for conservation biocontrol, but the effects on biodiversity conservation in Australia are simply not comparable with the UK (see Lonsdale *et al.* 2003).

Research on a broader array of GMOs Much of the focus of GM risk research has been on GMHT and insect resistant crops. CSIRO established a GMO ecology group with the brief to study the environmental risks of a much broader array of GMOs than just these crops. Although Bt cotton was studied, the work involved hitherto little studied interactions such as:

- impacts on soil processes; and
- interactions of the crop with higher trophic levels such as predators and parasitoids.

Novel GM types that were studied were:

- GM pasture legumes (their impact on herbivorous pasture insect pests and their potential to invade native grasslands); and
- two very diverse GMO types that are much further from field release (5–10 years) – mouse cytomegalovirus (for sterile feral control of mouse plagues), and plants containing viral sequences.

Interaction between these activities has been engendered by technical/policy workshops that brought together the researchers and regulators, so that the results can inform the regulatory systems and management guidelines. To safeguard the perceived impartiality of the work, CSIRO's Chief Executive stipulated that, while external coinvestment was to be sought, the research was only to be funded by public good sources – chemical companies were out of scope.

DISCUSSION

If GM crops are to be taken up, the community may demand:

1. comprehensive long term monitoring schemes;
2. emergency response plans; and
3. systems designed to minimise cross-contamination of different value chains.

The design and implementation of these schemes will obviously require input from scientists. While much risk management research will need to be specific to the GMO in question, there will also be a need for generic research such as (i) translating generic findings into monitoring frameworks, (ii) linking up with biosecurity researchers to gain insights from past incursion response, and (iii) designing farming systems that are more robust to unforeseen hazards.

It has become clear that research into the environmental risks of GMOs will be held up to very detailed scientific scrutiny. Ecologists will have their work examined critically in a way that few of us in any discipline are used to. Some key steps for increasing rigour would include:

a. review of the proposed methodology by scientists external to the project;
b. rigorous determination of sample size and experimental duration;
c. testing of hypotheses based on mechanisms rather than simply 'looking for disasters' (e.g. 'I hypothesise that the insertion of this gene into that plant will have effect *x* on component *y* of the soil fauna, based on my knowledge of the plant-soil community interaction web');
d. reliance on peer-reviewed journals rather than conference proceedings or internal reports (cf. the UK Farm Scale Evaluations) to avoid accusations of 'junk science'; and
e. placing the study in a risk assessment framework so that its limitations are more apparent (see Lonsdale 2002).

REFERENCES

Carr, S. (2000). 'EU safety regulation of genetically modified crops.' (The Open University, Milton Keynes, UK. ISBN 0 7492 8433 1).

DEFRA (2003). Information on GM crops (includes links to the Farm-Scale Trial). www.defra.gov.uk/news/issues/gmcrops.asp.

Fairbrother, A. and Bennett, R.S. (1999). Ecological risk assessment and the precautionary principle. *Human and Ecological Risk Assessment* 5, 943-9.

Firbank, L., Heard, M., Woiwod, I., Hawes, C. *et al.* (2003). An introduction to the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. *Journal of Applied Ecology*, 40, 2-16.

Hayes, K.R. and Sliwa, C. (2003). Identifying potential marine pests – a deductive approach applied to Australia. *Marine Pollution Bulletin* 46, 91-8.

Kowarik, I. (1995). Time lags in biological invasions with regard to the success and failure of alien species. *In* 'Plant invasions – general aspects and special problems', eds P. Pysek, K. Prach, M. Rejmanek and M. Wade, pp. 15-38. (SPB Academic Publishing, Amsterdam).

Lonsdale, W.M. (2002). GMOs: risk, environment and perception. Biotechnology of *Bacillus thuringiensis* and its environmental impact. Proceedings of the 4th Pacific Rim Conference, ed. R. Akhurst, pp. 239-43. (CSIRO Entomology, Canberra).

Lonsdale, W.M., Baker, G., Godfree, R., Hirsch, M., Williams, K. and Yeates, D. (2003). Findings from the UK Farm Scale Evaluation of Genetically Modified Herbicide Tolerant crops – an appraisal of their implications for Australia. Report to Minister for Science. (CSIRO Entomology, Canberra).

NRC (National Research Council) (1989). Conclusions and recommendations: plants. *In* 'Field testing genetically modified organisms: framework for decisions', pp. 70-6. (National Academy Press, Washington, DC).

Parker, I.M. and Kareiva, P. (1996). Assessing the risks of invasion for genetically engineered plants: acceptable evidence and reasonable doubt. *Biological Conservation* 78, 193-203.

Perry, J., Rothery, P., Clark S.J., Heard, M. and Hawes, C. (2003). Design, analysis and statistical power of the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. *Journal of Applied Ecology* 40, 17-31.

RCEP (Royal Commission on Environmental Pollution). (1991). 'GENHAZ: A system for the critical appraisal of proposals to release genetically modified organisms into the environment.' (HMSO, London, UK).

Smith, C.S., Lonsdale, W.M. and Fortune, J. (1999). When to ignore advice: invasion predictions and decision theory. *Biological Invasions* 1, 89-96.

Stirling, A. (2001). The precautionary principle in science and technology. *In* 'Reinterpreting the precautionary principle', eds T. O'Riordan, J. Cameron, and A. Jordan, pp. 61-94. (Cameron May, London).

Strauss, H.S. (1991). Lessons from chemical risk assessment. *In* 'Risk assessment in genetic engineering', eds M.A. Levin and H.S. Strauss. (McGraw-Hill, New York).

Williamson, M. (1996). 'Biological invasions'. (Chapman and Hall, London).

Gene technology regulation in Australia: a framework for identifying, assessing and managing risks

Sue Meek
Australian Government Department of Health and Ageing, Office of the Gene Technology Regulator, PO Box 100, Woden, Australian Capital Territory (MDP 54), Australia

Summary This presentation on Australia's regulatory framework for gene technology, in the context of the session topic 'Biotechnology: the way forward?' introduces delegates to governmental and industry responsibilities in relation to the release of genetically modified crops into the Australian environment.

The presentation outlines a number of features of the gene technology regulatory scheme with particular emphasis on how the Office of the Gene Technology Regulator (OGTR) undertakes the scientific evaluation of risks that genetically modified organisms (GMOs) may pose to human health and safety and the environment. It will also explain why the evaluation and management of certain issues including economic impacts (e.g. marketability and agricultural trade) and alternative technologies are excluded from consideration. Risk management strategies to minimise the likelihood of identified hazards occurring, including research initiatives required, or sponsored by, the OGTR to inform risk management measures will also be discussed.

The governance framework established by the *Gene Technology Act* 2000 and the respective roles of the Gene Technology Regulator, expert advisory groups, State and Territory Governments, Australian Government agencies and authorities, and the involvement of the public in the evaluation of licence applications are explained.

Keywords Gene technology, regulation, GMO, risk assessment, risk management.