

Plant Genomics

Background Paper^{*}: Genomics for Biodiversity, Conservation and Land Use

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Background to the ESRC Genomics Forum

The ESRC Genomics Forum was established in 2004 as part of the UK-wide ESRC Genomics Network (EGN), which is charged with undertaking ‘a systematic, critical and technically informed exploration of the past, present and future economic and social trajectory of genomics’. The Genomics Forum aims to build bridges between science, social science and public policy in the area of genomics, to exploit synergies across the ESRC Genomics Network Centres and other relevant ESRC investments, to encourage interaction with the range of genomic scientists, and to assist with the engagement of policymakers and publics.

Project remit and themes

This project is broad in scope, addressing the trajectory of plant genomics in a holistic sense. We will aim to discuss the potential and the limitations — technical, social, regulatory or otherwise — of developments in plant genomics research in three main areas: (1) biodiversity, conservation and land use, (2) farming and the bioeconomy, and (3) alien species and biosecurity. These areas are not often considered together within the scope of a single project, but each can be seen as a driver for plant genomics research. We hope to identify areas of common ground, possible gaps in current research, and issues that cut across these platform themes (for example, climate change, food security and ecosystem services). We hope to foster dialogue between stakeholders involved in all aspects of plant genomics research, with the ultimate goal of informing and influencing UK policy.

Definitions

We will accept the broad definition of *plants* outlined in the UK Plant Diversity Challenge (2004), to include algae, bryophytes, fungi, lichens and vascular plants. We also propose to include *soil microorganisms* in this study, owing to their importance for plant development and growth, and the growing interest in profiling soil microbial communities using genomic technologies (Gewin, 2006).

The total DNA content of an organism is referred to as its *genome*, and includes genes, the regulatory DNA sequences that control gene expression, and non-coding DNA. Simply put, *genomics* is the study of genomes. It is a *systems approach* that involves the generation, integration and analysis of large datasets in order to map the location, structure and function of genes. Genomics differs from *genetics* in its emphasis on studying the simultaneous effects of multiple genes on an organism, instead of focusing on the effects of a single gene. Medicine, drug development, agriculture and the biotech industry are four areas for which genomics is often cited as having great potential.

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Plant genomics: issues of biodiversity, conservation and land use

The following notes are intended to stimulate discussion rather than provide a comprehensive overview.

1. Current initiatives in plant genomic research

There are several ongoing genomics initiatives relevant to plant conservation and biodiversity, including:

- Plant genome sequencing projects: 3 genome sequences completed, a further 6 underway, and many more genetic maps and large-scale EST databases¹ being generated for principal food crops, model organisms and other plant species²
- Barcode of Life – the British Flora: UK plant barcoding initiative that aims to catalogue plant species on the basis of specific DNA sequences. With regards to conservation, such information might prove useful for the rapid assessment of community biodiversity and for forensic purposes (e.g. identifying illegally imported plants or pathogens). Larger, international barcoding initiatives include the Consortium for the Barcode of Life (CBOL) and the Census of Marine Life (CoML).
- The creation of germplasm and seed banks (e.g. the Millenium Seed Bank at Kew and the new seed storage facility being built in Svalbard, Norway) to document and preserve natural genetic diversity in plants³.
- The creation of databases for compiling information relating to plant genetic studies (for example, the Genetical Flora of the British Isles database hosted by the Royal Botanic Garden Edinburgh). Developing rational and biologically based approaches to organizing and analysing vast quantities of genetic data remains a challenge. Integrating genetic information with existing morphological, distribution and conservation data is also a formidable task.
- Genomic profiling of soil and marine microbial communities: using genomic technologies to generate microbial ‘fingerprints’ for soil and ocean samples (e.g. Venter *et al*, 2004, Gewin, 2006)
- The application of conservation genetics and the emerging field of community and ecosystem genetics

Genomics is essentially an information-providing tool, and may prove useful for linking cause and effect in environmental issues. It is important to consider how the nature and content of genomic information is influencing the various stakeholders involved in issues of plant biodiversity and conservation (conservationists, farmers, amateur experts, general publics, advocacy groups, media, natural scientists, social scientists, policymakers, etc.).

¹ EST: expressed sequence tag

² See <http://www.ncbi.nlm.nih.gov/genomes/PLANTS/PlantList.html> for a list of ongoing projects.

³ Although seed banks are undeniably useful for conservation projects, there is some debate regarding the merit of such sites for long-term food security and preservation of genetic diversity. As most seeds cannot be stored for more than about 40 years, seed banks must preserve their material by growing plants in greenhouses, field plots or laboratories at regular intervals (Graner & Börner, 2006). And what about the soil microbial diversity necessary for plant growth in different environments? Arguably, seed banks are only part of the solution for long-term preservation of genetic diversity.

2. Goals for conservation research — conserving biodiversity

‘Biological diversity’, or biodiversity, has no single definition but is typically understood to indicate the variety of life on earth, including genetic diversity within a species, and diversity across species and ecosystems⁴. Threats to biodiversity include habitat loss and fragmentation, introduced species (including non-native species and genetically modified organisms), pollution, overexploitation of biological resources, and climate change. Many of the actions that harm biodiversity simultaneously provide societal benefits, but this trade-off is poorly defined (Tilman, 2000). For example, how should potential conflicts between farmers and species vulnerabilities be resolved? Can biodiversity and ecosystem services be quantitatively evaluated in terms of their economic benefits and contributions to human well-being, or do we simply have a moral obligation to conserve biodiversity (McCauley, 2006)? Solutions are typically developed through a process of negotiation, and should not consider science, economics or public attitudes in isolation.

Scientifically, there is no single or most appropriate measure of biodiversity, but common measures typically include species richness (the number of species in a given area), species composition (the types of species present), and species diversity (a function of species richness and abundance). Genomics may offer additional measures of diversity at a genetic level (see sections 3, 4). On average, increased diversity is thought to lead to increased productivity, increased nutrient retention, and greater ecosystem stability and adaptability (Tilman, 2000, Hooper *et al*, 2005, Gregory *et al*, 2006). But how important is biodiversity relative to other factors that influence ecosystem functioning, such as climate, soil type and disturbance regime?

Probably the main goal for conservation research is to conserve biodiversity. In practice, conservation initiatives focus on different aspects and/or levels of biodiversity (for example, the UK Habitat and Species Action Plans)⁵. Maintaining ecosystem interactions and processes is becoming an increasing focus for conservation practice. In what way(s) might genomics prove most useful for conservation? (e.g. for setting conservation targets; risk assessments; monitoring outcomes; profiling at the level of species, communities or ecosystems; determining appropriate control methods, etc).

Conservation is a ‘crisis discipline’, and it has been argued that conservation decisions and practices are based largely on anecdotal sources instead of formal scientific evidence (Sutherland *et al*, 2004a). There has been a recent push for a more formal structure to evidence-based conservation (e.g. Ferraro & Pattanayak, 2006, Sutherland *et al*, 2004b), with the creation of databases⁶ (including the June 2006 launch of the UK Nature Barometer website by the Joint Nature Conservation Committee) and monitoring of conservation actions. A clear, evidence-based process (that takes into account not only scientific information but also social and economic considerations) would probably result in increased funding for conservation projects. Would it also increase the success of conservation initiatives?

Despite marked increases in the amount of data available on biodiversity distribution and rates of change, integrating this information with the policy community is a recognized problem, in part owing to the fragmented nature of the biodiversity scientific community (Dirzo & Loreau, 2005).⁷ A recent commentary in *Nature* calls for the creation of an international panel of experts on biodiversity, similar to the Intergovernmental Panel on Climate Change (IPCC), which would help to link scientific expertise with policymaking in a formal framework (Loreau *et al*, 2006). The French government is currently funding an 18-month consultation process to assess possible models for such a panel (www.imoseb.net).

⁴ The definition adopted by the Convention on Biological Diversity is “the variability among living organisms from all sources...and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems” (CBD, 1992).

⁵ The UK Biodiversity Action Plan (UKBAP) is apparently also developing Genetic Action Plans.

⁶ Notably, existing databases seem to contain either genetic or ecological information, rarely both together.

⁷ The appropriate management and integration of large quantities of information is an issue that also arises repeatedly in the context of ‘-omics’ technologies.

3. Conservation genetics

“there needs to be a wider awareness that genetic information can place conservation decisions in context...however, conservation genetics itself needs to be placed in the context of the difficulties of working across political boundaries, amidst economic challenges and in the face of the complexity of using science to inform management decisions” (DeSalle & Amato, 2004)

The proliferation of genomic technologies, including high-throughput sequencing, microsatellite analysis and non-invasive DNA sampling, is leading to an increased role for genomics in plant conservation. Compared to animal and human genetic studies, plant genetics is complicated by the often large size of plant genomes and their varied reproductive strategies (sexual/asexual reproduction, hybridization, mode of fertilization, etc). Genetic information can prove instrumental for *ex situ* species breeding, for addressing species-boundary questions, and for assessing levels of genetic pollution (for example, as a result of GM crops or introduced plant species). Genetic studies also help to create a more accurate picture of *pattern* and *process* in endangered species, and can in theory be integrated with ecological and landscape approaches to conservation (DeSalle & Amato, 2004).

Genetics now seems to be an important tool for the development of conservation strategies at the level of individual species, certainly in the UK. Informed decisions regarding plant population management, particularly for threatened species, are best made with a good understanding of their population structure, environmental requirements and reproductive strategies. Detailed information regarding species taxonomy, hybridization patterns, genetic diversity, gene flow and minimum viable population size can now be obtained using genetic techniques. A convincing conservation proposal would include all of this information, together with ecological and biological assessments⁸.

Note that genetics is by no means sufficient for developing a conservation proposal, but can be used to complement existing morphological and distribution data⁹. In this sense, although genetics/genomics might not be formally incorporated into conservation policy, it may prove an increasingly important factor in determining funding success for conservation projects. Genetic information seems particularly important for restoration projects, to ensure that the replanted population is of sufficient size and genetic diversity to sustain itself. A nice example of the integration of genetics and ecology in conservation proposals was recently published by the Scottish Montane Willow Research Group (2005).

The UK Population Biology Network (UKPopNet) recently held a workshop addressing a wide range of theoretical, practical and policy issues in conservation genetics. Their report summarizes current trends and questions in conservation genetics, highlights a number of knowledge gaps, and provides some concrete recommendations for future practice (Gregory *et al*, 2006).

One caveat to the current use of genetic/genomic information for conservation assessment purposes is that it represents a snapshot in time, and as such becomes more useful if there is a ‘benchmark’ or frame of reference. The determination of appropriate benchmarks from which to make conservation decisions is an issue more broadly relevant to conservation planning. A similar question for conservation planning and policy is whether there are sets of ‘indicators’ that can serve as representative markers of trends in biodiversity¹⁰. The use of genomics and biomarkers may enable more sophisticated measurements of ‘harm’ for ecosystems and/or species.

⁸ Note that this information is very similar to that required for risk assessments of transgenic plant varieties (see OECD Consensus Documents for the Work on Harmonization of Regulatory Oversight in Biotechnology, http://www.oecd.org/department/0,2688,en_2649_34387_1_1_1_1_1,00.html).

⁹ The inventory of flora in the UK/Europe is fairly complete, unlike in much of the developing world — hence the use of the UK as a test site for plant ‘barcoding’.

¹⁰ See <http://www.defra.gov.uk/wildlife-countryside/biodiversity/biostrat/indicators/index.htm>

4. Community and ecosystem genetics/genomics

Understanding how complex ecological communities develop is a recognized frontier in biology (Thompson *et al.*, 2001). Can genetic and genomic technologies be used to inform our understanding of complex communities and our approaches to conservation at the habitat/ecosystem scale?

The emerging field of community and ecosystem genetics focuses at the level of genetic interactions between species and their environment, and in so doing hopes to understand the genetic/heritable basis of ecosystem processes and the effects of external factors (such as climate change and the introduction of new species) on entire communities (Whitham *et al.*, 2006). A current focus in ecosystem genetics is to try and understand the genetic interactions between foundation species¹¹ and their dependent community members over time, to address how gene–environment interactions affect community structure, ecosystem processes and ecosystem evolution.

One finding emerging from such studies is that genetic diversity in common, non-endangered foundation species is important for maintaining community biodiversity (Bangert *et al.*, 2005, Shuster *et al.*, 2006). Conservation biologists recognize that there is a minimum viable population size necessary for the continued existence of a given species. However, for a foundation species, the minimum population size necessary for survival of the species may be different from the minimum population necessary for the survival of the dependent community. This has led to the concept of a minimum viable *interacting* population¹², and suggests that non-endangered foundation species may also be important targets for conservation efforts, especially in the face of climate change (Whitham *et al.*, 2006). How should this be reflected in policy?

In parallel with advances in community and ecosystem genetics, genomic approaches are also helping researchers to gain an understanding of the molecular basis of ecosystem adaptation and evolution. Exhaustive genome sequencing for all organisms in an ecosystem is not currently possible, but shallow sequencing of organism consortia (for example, soil microorganisms) can provide insights about the composition and genetic diversity of a community that may have implications for ecosystem functioning (Whitham *et al.*, 2006). Metagenomics¹³ is a term originating in microbial ecology, and refers to genome-based analyses of communities of interacting organisms in diverse ecological contexts (Dupré & O'Malley, forthcoming). The concept of the 'community metagenome' is also prevalent in microbial ecology, and essentially considers the genomes of co-occurring species as a collective genetic resource. This idea could in theory be extended to macro-organisms as a way of describing ecosystem composition and structure — would it prove helpful in conservation practice?

Genomic technologies and the types of information they provide promote a more distributed, systems-based understanding of ecosystem functioning, and enable a shift of focus to the level of species interactions. This shift is paralleled at a practical level in several ways (for example, in the 'ecosystem approach' to conservation advocated in the Convention on Biological Diversity¹⁴).

¹¹ Foundation species are those that structure communities by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes (such as nutrient cycling). Foundation species in communities are generally identified as plant species, and the plant–soil interface seems key for stabilizing fundamental ecosystem processes.

¹² The minimum size of a foundation population that is required to maintain genetic diversity at levels required by dependent and interacting species.

¹³ Metagenomics has also been referred to as environmental genomics, community genomics, ecogenomics or population genomics.

¹⁴ The principles of the ecosystem approach are outlined on the CBD website, together with examples of projects that have used this strategy (<http://www.biodiv.org/programmes/cross-cutting/ecosystem/default.shtml>).

5. Plant conservation in the UK: policy and practice

By definition, biodiversity spans several levels of biological organization (genes, species, ecosystems), and cannot be measured by simple universal indicators. Despite the existence of several global and regional frameworks¹⁵, the practical implementation and management of biodiversity conservation strategies end up being predominantly national and local issues.

UK Policy

Provision for nature reserves and Sites of Special Scientific Interest (SSSIs) in the UK was first set out in the National Parks and Access to the Countryside Act of 1949. The Wildlife and Countryside Act (1981) provides a legal foundation for the conservation of wild plants in the UK. This framework has since been strengthened by the Countryside and Rights of Way Act (2000) for England and Wales, the draft Nature Conservation (Scotland) Bill and the Environment (Northern Ireland) Order (2000).

In response to the 1992 Convention on Biological Diversity, the UK has developed its own Biodiversity Action Plan (1994) for flora and fauna, which currently includes 391 species action plans, 45 habitat action plans and 162 local biodiversity action plans. A more specific Global Strategy for Plant Conservation was published in 2002, from which the UK has again developed its own Plant Diversity Challenge (Cheffings *et al*, 2004), containing 16 outcome-oriented targets to be met by 2010.¹⁶

A recent paper by Delbaere (2006) highlights trends in European biodiversity conservation policies, including the integration of biodiversity considerations into other policy frameworks (such as agriculture, transport, housing, etc.) and a move from policy development and implementation to the evaluation of effectiveness. The need for coordination of agriculture and biodiversity strategies has been highlighted by the ACCELERATES project¹⁷, which integrated various existing models to examine the effect of climate change on land use and biodiversity in agro-ecosystems (Rounsevell *et al*, 2006).

This push for policy integration reflects a more general shift in policymaking away from ‘government’ (a top-down, process-based legislative approach) towards ‘governance’ (a more distributed, outcome-oriented approach). Governance strategies focus on “the coordination of multiple actors and institutions to debate, define and achieve policy goals in complex political arenas” (Lyll & Tait 2005, p.4). Indeed, the development and implementation of plant conservation policy in the UK involves multiple institutions and stakeholders, and is largely set around achieving and maintaining certain targets. In contrast, agri-environment schemes still seem to be largely process-based, encouraging farmers to implement one or more ‘wildlife-friendly’ strategies (see section 6).

The strong links between agriculture and environment mean that policies relating to one of the two areas are likely to affect the other — in enabling, constraining or neutral ways. In line with the push towards more integrated, holistic approaches to environmental management and sustainable development, it may be interesting to examine the intersection of biodiversity-related policies in the UK (including conservation, agricultural, and plant trade policies), to identify potential areas of conflict or mismatch for the various stakeholders affected by these policies.

¹⁵ Most notably the 1992 Convention on Biological Diversity (CBD), but also the 1973 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), the 1996 Global Plan of Action for the Conservation and Sustainable Use of Plant Genetic Resources for Food and Agriculture, the 1971 Ramsar Convention and the 1972 World Heritage Convention. European frameworks for biodiversity protection include the 1982 Bern Convention, the Habitats and Species Directive, the Natura 2000 network, the Pan-European Biodiversity and Landscape Strategy and the 2001 European Community Biodiversity Strategy. UK conservation frameworks are discussed in the main text.

¹⁶ In 2001, the EU committed to halting biodiversity loss by 2010.

¹⁷ ACCELERATES: Assessing Climate Change Effects on Land Use and Ecosystems: from Regional Analysis to the European Scale. This project was funded through the EC FP5 programme.

UK Practice

The UK Biodiversity Action Plans provide a practical framework for plant conservation in the UK, and the implementation of these plans is overseen by the UK Biodiversity Partnership, which comprises a wide range of individuals (amateurs and experts), businesses, government organizations and NGOs. In total, up to 100,000 people are involved in biodiversity action in the UK (English Nature *et al*, 2005).

One particularly valuable resource for biodiversity conservation in the UK is the vast number of ‘amateur expert’ naturalists, who together have an incredibly rich and diverse knowledge of both rare and common species. A recent ESRC-funded project on ‘Amateurs as Experts’¹⁸ has started looking at the nature and scope for interaction between networks of amateur experts, conservation agencies and policymakers in order to promote biodiversity conservation. How to harness the knowledge of amateur naturalists in a sensitive way, and combine it meaningfully with other scientific data, is a key issue for the development of effective conservation strategies. Encouraging amateur naturalists to participate in conservation projects is also very important. Are conservation projects becoming more reliant on scientific expertise? Do amateur experts typically view a genetic understanding of plant species as important?

At a progress meeting for the UK Plant Diversity Challenge in April 2006, a warning was issued that some of the priority targets will not be met by 2010 without increased resource commitment¹⁹. The generation of ‘improved knowledge’ to inform conservation activity was recognized as a key challenge. This will almost certainly include increased genetic understanding of threatened plant species.

In practice, plant biodiversity conservation and management in the UK is tightly interwoven with agro-ecosystem management, largely owing to the history of land-use patterns. Approximately 70% of the land in the UK is farmed and many British species (plant and animal) are adapted to living in a farmed landscape, so efforts to conserve wildlife are often concentrated within managed ecosystems and involve the maintenance of early successional habitats (POSTnote, 2005, Sutherland, 2004). In fact, the British countryside has been modified for so long that farmland is generally considered ‘natural’ landscape²⁰. Wildlife-friendly farming has therefore been promoted as a strategy for biodiversity conservation (see section 6). The ecosystem approach is also being developed as a more holistic, systems approach to conservation²¹. Is there a role for genomic technologies in facilitating such approaches?

The UK is also involved in a number of biodiversity conservation projects in the developing world. Government-led initiatives include those run through the Department for International Development (DFID) and the Defra-funded Darwin Initiative²². The Darwin Initiative was set up in 1992, and has so far committed £53 million to over 450 projects in 100 developing countries. All projects involve collaboration between a UK-based institute and the host country, and thus draw on British expertise in biodiversity conservation. What proportion of these projects make use of genetic/genomic technologies? Does the availability of such technologies change the nature of the conservation projects being undertaken in the developing world? Does the role of plant genomics in conservation work differ between the UK and the developing world?

¹⁸ <http://www.lanacs.ac.uk/fss/projects/ieppp/amateurs/team.htm>

¹⁹ <http://www.jncc.gov.uk/page-3698>

²⁰ In contrast with other regions of the world, where the ‘natural’ landscape is essentially ‘wild’ and untouched.

²¹ The JNCC has recently published a new strategy for nature conservation that emphasizes conservation at an ecosystem level, and advocates conservation at the species level when a more holistic approach fails to yield the desired results (Vincent, 2006).

²² <http://www.darwin.gov.uk/>

6. A broader perspective: links between conservation, agriculture and RELU

'*Land health*' was proposed by Aldo Leopold as a goal for land management (1946). Healthy land implies land that is fertile and productive, and is a concept that encompasses both agriculture and biodiversity/conservation. Soil fertility is a critical component of land health. The concept of land health "centres chiefly on the functioning of ecological processes and only indirectly on biological composition" (Freyfogle & Newton, 2002), which might align well with emerging 'systems' approaches to ecosystem management.

Land use and *land management* also relate to both agriculture and biodiversity/conservation, in allocating specific tracts of land for specific purposes (e.g. food crops, non-food crops, 'natural' habitat, managed parkland, etc.). Given the prominence of RELU (rural economy and land use) in the UK policy agenda, it might be worthwhile to consider whether genomics could influence our approach to land use in a broad sense.

- Strategies for conserving biodiversity include (1) land-sparing, which involves intensively farming agricultural land so as to maximize area for natural habitats, and (2) wildlife-friendly farming, where land is farmed less intensively and wildlife-friendly measures are implemented. Social, economic and environmental factors should be considered to determine the most appropriate land-use strategy. Economically, it might make sense to devote minimal farming effort to areas that will not show much return and to concentrate on potentially high-yielding farmland. This would result in a more 'patchwork' and segregated countryside — public acceptance? (Sutherland, 2004) And what effect might this have on biodiversity, given that many British species are adapted to living in farmed/managed habitats?
- **Agri-environmental schemes (AES):** the EU and European governments spend about €3.5 billion annually on AES schemes that encourage less intensive farming and promote gains in biodiversity, landscape preservation, soil quality and water conservation²³. To date, no cost-benefit analysis is available for these schemes because targets have not been set and data not collected (John, 2006a). Although such schemes are unlikely to have negative effects on wildlife, there is no great evidence to suggest that they are better for biodiversity than conventional agriculture — when biodiversity increases have been noted, they are typically in common species²⁴ (Whitfield, 2006). Would it be more effective to pay for environmental outcomes instead of managerial practices? But then monitoring/enforcement practices would be required. Is there a role for genomics in such surveillance? The Environment Agency seems to think so (October 2003 report), but monitoring and diagnostic tools have to be standardized and yield reproducible results²⁵.
- **The Common Agricultural Policy** encouraged intensive agriculture by linking production to the subsidy payment. With the recent decoupling of these payments from production, farmers will be given a single payment irrespective of what they do, as long as the land is maintained in suitable agricultural and environmental condition. This stands to alter land-use patterns in the UK. The incentive is now for farmers to manage their land in the most cost-effective manner — agriculture may become less intensive, or cease altogether in areas where it is not economically viable. Using agricultural land to grow 'carbon-neutral' energy crops might be an option if agricultural patterns are to change (John, 2006b). Consider shifting subsidies away from agriculture²⁶ and towards environmental protection, tourism, etc? (James *et al*, 1999) Tourism is more economically important to the UK than agriculture (Sutherland, 2004).

²³ A new Environmental Stewardship scheme was launched in England in March 2005, replacing all previous agri-environment schemes. All farmers and landowners can participate in the entry-level scheme, which is meant to be complementary to other conservation measures such as the Biodiversity Action Plans (POSTnote, 2005).

²⁴ Of course, the definition of 'biodiversity' used would almost certainly affect the perceived success of the schemes.

²⁵ Similarly, the US Environmental Protection Agency's *Interim Policy on Genomics* (2002) states that genomics data alone are insufficient as a basis for risk assessment and management decisions at present (Dix *et al*, 2006).

²⁶ New Zealand could be studied as a possible example of what might happen to agriculture and land-use patterns when agricultural subsidies are removed.

7. A broader perspective: links between genetics, conservation and climate change

There is increasing evidence that global changes in climate are influencing biodiversity and ecosystem functions at several levels, for example, affecting species distributions, phenology and species interactions (Delbaere, 2005). Any long-term strategies for conservation or land use should take account of how habitats and ecosystems might be affected by climate change. Focusing at the landscape level and establishing buffer zones and 'wildlife corridors' are possible strategies for promoting species migration and connectivity. How can biodiversity conservation policies take into account the dynamics of changing conditions in protected areas? Arguably, the creation of new habitats as well as the conservation of existing ones will be necessary, and conservation strategies will have to become more flexible in order to deal successfully with climate change (UKCIP, 2001).

The Defra-funded UK Climate Impacts Programme (UKCIP) was set up in 1997, and coordinates research on the effects of climate change at regional and national levels²⁷. The UKCIP MONARCH project²⁸ uses computer modelling to evaluate the effect of climate change on wildlife and geomorphological features in the UK. Phase I of the project combined data on climate change with distribution data for 50 plant and animal species associated with 12 habitats of conservation concern in the UK, to predict future species distribution. Climate change was predicted to present threats for some species and opportunities for others (UKCIP, 2001). Can genetics/genomics help us to identify vulnerable species with increased certainty? Phase II of MONARCH focused on a more local and regional level, downscaling the model to 1-km² resolution in four case-study areas²⁹.

Community and ecosystem genetics are proving valuable in terms of understanding how the genetics of foundation species affects other species in a given ecosystem (see section 4), and may be useful for understanding ecosystem responses to climate change. Focusing conservation efforts on foundation species (even if they are not among the most threatened species) might promote ecosystem functioning in the face of climate change. How might this affect conservation policy? Climate change and global warming may also have important ramifications for non-native exotic plants, which may be better adapted to a warmer climate than some native British species. How should the UK deal with non-native species that are being pushed out of their native territories and would be suited to growing in the UK?

See also section 2 for possible parallels between conservation efforts and the ongoing approach to studying climate change by the IPCC.

²⁷ <http://www.ukcip.org.uk/default.asp>

²⁸ MONARCH: Modelling Natural Resource Responses to Climate Change

²⁹ http://www.ukcip.org.uk/resources/publications/pub_dets.asp?ID=81

8. Some questions

1 - *In what way(s) is genomics already useful for conservation? How does this stand to change?*

2 - *Is there a need for better integration between conservation ecology and conservation genetics? Is there a need for better integration between conservation genetics and developments in agricultural genetics? If so, how might this integration be promoted/achieved?*

3 - *What can we learn from studies of animal genomics when it comes to plant conservation?*

4 - *Can genomics be used for predictive purposes when it comes to conservation? For example, can it predict which species are susceptible to particular pathogens or might be lost from natural communities as a result of climate change?*

5 - *Given limited resources, how should we decide which species to characterize genetically? Should we focus on those at risk of extinction? On foundation species? According to national/local research expertise?*

6 - *Is there a consensus on how should we approach plant conservation under conditions of climate change? If a species is no longer suited to its location owing to changes in climate, should we attempt reintroduction in a more suitable location? Should we introduce new plant varieties to a given area? Should we exploit natural genetic diversity to look for heartier variants? Should we genetically engineer heartier variants?*

7 - *In the UK, most plant genomics research for conservation purposes seems to be concentrated in the academic sector. Are there any examples of private investment or public-private partnerships in conservation biology? Are there any such opportunities?*

8 - *Are there any patenting/IP issues relating to plant genomics for conservation purposes?*

9 - *Does the role for plant genomics in conservation differ between the UK/Europe and the developing world?*

10 - *Are there potential negative consequences for using genomics in conservation efforts?*

11 - *Decisions regarding land use involve balancing issues related to climate, soil and water with effects on landscape, social acceptance, biodiversity and the rural economy. Is there a role for plant genomics in determining appropriate land-use strategies? If so, how can it be used to best effect?*

12 - *There seems to be a general push for developing more integrated policies relating to conservation, agriculture, environmental pollution and land-use. Are there inconsistencies between existing policies in these areas? Could these policies be better integrated to result in fewer conflicting messages for the numerous stakeholders?*

13 - *Are there potential issues of public acceptance regarding the use of genomics for plant conservation purposes? How do NGOs view the use of genomic technologies for conservation purposes? Can we learn anything from previous situations involving public acceptance of plant genetic technologies? (for example, GM crops)*

14 - *Should there be a 'formal' role for genomics in policy relating to plant biodiversity? (e.g. as a monitoring tool for environmental pollution, soil health, pathogen detection and GM contamination)*

15 - *How might genomics be incorporated into more efficient regulatory regimes for environmental protection?*

9. References

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