Environmental Omics – small molecules big impact

Workshop of leading experts
20 May 2010

Word for Word Report

Workshop Facilitator	**Diana Pound**	dialogue matters
	Jim White	dialogue matters
	Lucy-Anne Bishop	dialogue matters
	Sarah Turner	**CEH**
	Norman Morrison	Univ of Man
	Eddie Brede	Univ of Cardiff
	Ceri Morris	Univ of Cardiff
	Paul Fisher	Univ of Man
	Tim Booth	CEH
Outputs typed by:	**Beverley Charlton**	**CEH**
Processed and sorted by:	**Diana Pound**	dialogue matters
	Lucy-Anne Bishop	dialogue matters

Contents

About the workshop and this report

▪ Purpose of the workshop

The workshop was to bring key figures from the Environmental Omics research community together to discuss priorities for funding both in terms of strategic new research ideas and how the community can function more effectively and collaboratively.

These outputs are being used together with the results of a questionnaire and other input to inform CEH's recommendations to NERC for Environmental Omics work over the next 10 years.

▪ About this report.

The discussion was recorded on flip charts or 'post-it' notes. Following the workshop these have been typed 'word for word' as written and then sorted to put similar ideas together from within a conversation. This is to aid understanding. This report follows the same order as the event.

▪ Why sort the outputs?

Conversations do not progress in a linear fashion but go off at tangents, circle back and change direction suddenly. As a result, it can be very difficult to make sense of a dialogue when it is reported in the sequence in which it happens and important themes and ideas can be obscured.

It is for this reason that the outputs of the workshops are sorted and grouped.

The sorting is done by 'emergent analysis' ie seeing what themes emerge rather than to a predetermined set of titles. The ideas could have been grouped differently, or different titles chosen, so no weight should be attached to them.

Whilst this report serves as a record of what was discussed, and an *aide memoir* for those who took part in the workshop, the contents are inevitably quite cryptic in places so it is strongly recommended that it is not used as a means of communicating with non–participants without proper explanation.

▪ Explanation about the format

Numbers denoted like this: <3> are the reference number for the participant who made the comment so that if needed the information can be followed up at a later point

Coloured text denotes the comments from one of the working group - the text is kept in colour so that even thought it is clustered together the comments from a particular group can be traced

Acronyms used in this report	Meaning
ACC	American Chemical Council
AHRC	Arts and Humanities Research Council
BBSRC	Biological Biomedical Science Research Council
CBOL	Consortium for the Barcode of Life
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CEFIC	Conseil Européen de l'Industrie Chimique – European Chemical Industry Council
CEPAS	Centre Ecologique de Port-au-Saumon, Charlevoix, France
CSIRO	Commonwealth Scientific and Research Organization (Australia)
DEFRA	Department for Environment, Food and Rural Affairs
DOE	Department of Environment
DMS	Dimethyl Sulphide
EG	Environmental Genomics
ELIXIR	European Life Sciences Infrastructure for Biological Information
EPA	Environmental Protection Agency
EPSRC	Engineering and Physical Sciences Research Council
ERA-NET	European Research Area - Networking
ERC	European Research Council
ERFF	Education and Research Fellowship Fund
ESF	European Science Foundation
FERA	Food and Environment Research Agency
FP7	Seventh Framework Programme for Research and Development
GOS	Global Ocean Sampling Expedition
GSC	Genome Standards Consortium
HEI	Higher Education Institute
KT	Knowledge Transfer
LoLa	Longer and Larger (grants)
LTER	Long Term Ecological Research (network)
LWEC	Living With Environmental Change
MRC	Medical Research Council
NBAF	NERC Biomolecular Analysis Facility
NCBR	National Centre for Biomolecular Research, Brno, Czech Republic
NCEAS	National Center for Ecological Analysis and Synthesis (California)
NEON	National Ecological Observatory Network
NEBC	NERC Environmental Bioinformatics Centre
NERC	Natural Environment Research Council
NGO	Non-Government Organization
NGS	Next Generation Sequencing
NHM	Natural History Museum
NSF	National Science Foundation (US)
PG&P	Post Genomic and Proteomic
R	A software package for statistics and graphing.
RC	Research Council
REF	Renewable Energy Foundation
RIVPACS	River Invertebrate Prediction and Classification System
RTD	Research, Technology and Development
SCRI	Scottish Crop Research Institute
SEPA	Scottish Environmental Protection Agency
SGPA	Special Groundwater Protection Area
TSB	Technology Strategy Board
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

1 It is 2030 and development and use of Omics knowledge has made an amazing difference. You and others are chatting and start listing the things that you can now do that have make the biggest difference to how we understand and use the environment. For you the top three things are……..

We have greater understanding of biodiversity

….understanding the diversity of life

- We know how many species there are.
- Make biodiversity assessment quicker and more efficient and exhaustive.
- Quick assessment of complete biodiversity from environmental samples.
- Reconstructing the species diversity of entire communities using rapid environmental samples.
- Integrated understanding of whole biological system/ecosystems and interactions.
- Genomes for >90% of life forms sequenced, fully annotated with NO GAPS IN FUNCTION.
- Community genomics has allowed us to understand the interdependence of all life.
- Patterns of species richness and turnover on Earth.
- The phylogeny and evolution of genomes from whole-genome sequences of all (most) species.
- I can sequence the genome of VIRUSES* from single copy templates independent of host system. *There are 10^{31} in the oceans!
- I can now understand 'within species' biodiversity – how organisms have moved around in time and space.

….understanding ecosystem processes and functions

- Integrated understanding of whole biological system/ecosystems and interactions.
- Quantify the importance of diversity on ecosystem function through a mechanistic understanding of functional diversity and redundancy.
- Describe the abundance, diversity and functional capacity of all bacterial genomes in an environmental sample (based on statistically relevant set of samples).
- Community Functional Description "Foodweb".
- I can accurately model the interactions from single cells through to entire communities.
- Understand processes from genes to ecosystems.

…. Understanding our effect on diversity

- The influence that man has on species diversity and modification of human behaviours to take this into account.

….. tracing connections and origins

- Traces of microbes with strong phylogenetic affiliation to Archaebacteria were found in underground caverns on Mars.
- It turns out that distinctions between individuals in populations are not true. They are all integrated at an epigenetic level.

…..finding climate change indicators

- Identifying individuals and species vulnerable to climate change.

….recreating lost iconic animals

- … the debate turns to whether resurrecting mammoths and woolly rhinos was a good idea.
- Recreating extinct organisms have allowed us to understand lost ecosystems.

We understand environment and human health interactions

…. Monitoring pollution and understanding risks and thresholds

- Monitoring environmental effects of pollution - understanding better the molecular basis of environmental toxicity.
- Well understood threshold limits based on an understanding of mechanisms of chemical toxicity in man and other species. In short, a much improved understanding of actual risk to all species from environmental change.

….. understanding links of environmental change and human health

- A greater understanding of how environmental change, natural or man-made, impacts on human health, taking into account inte-rindividual differences that lead to susceptibility and resistance.

- Predictive Environmental Health – wildlife and human. No longer a disease/pollution focus. Addressing causes and effects.

We understand more about adaptation

- Resolving the genomic basis of adaptation.
- Better 'genomic scans' for adaptation/speciation genes.
- Genome-wide understanding of fitness.
- How organisms adapt – genomically – to environmental perturbations (selected examples).
- Understanding better the importance of biodiversity and adaptation.
- Understanding acute responses to stimuli and long-term adaptation by fast multi Omics.
- I can find the genes underlying local and species adaptation, for example understand why and how an organism is adapted to its environment.
- Identify genes responsible for key adaptations.
- Accurate link between response and impact to enable interpretation of potential effects on organisms.

Access to Data makes a big difference

…. We have access to data

- Free access to all Omics data regardless of whether the research was carried out by a UK/European/Worldwide university or industry.
- Well-integrated data in databases will lead to better understanding of gene/environment interactions.
- Ability to address environmental questions using purely <u>in silico</u> approaches on archived data – free access to data.

…..Availability of data means we spend more time thinking and analysing not collecting

- Most data is in databases, (hopefully) well organized and available for analysis. Scientists do what they should – thinking and analysis instead of spending years in a laboratory.
- Had we been even better prepared to meet the bioinformatic challenges in the 2010s science would probably have moved forward even faster.
- Now that we are generating whole community profiles using DNA sequencing and systems biology studies we can access all data easily online to test and generate new hypotheses.

Working effectively with others

…..WE collaborate with expert and visionary users

- Can recruit scientists/find collaborators/colleagues who may not be expert users but are Omics literate and have realistic and yet visionary views on how to use the approaches.
- The breadth of uptake of all the Omics technologies, across the widest environmental community, through collaborations we would never have thought of.

….. we are joined up

- Omics funding organizations joined up. Within UK and internationally.

Systems Biology

- Knowing functions of all the biomolecules.
- Network analysis and gene cascades.
- Genotype ↔ Phenotype.
- Link Structure to Function.
- Resolving the '- Omic -' systems basis of phenotypic plasticity.
- Complete understanding of how much (if any) an ome is 'noise' *versus* 'signal' and the factors which determine this ratio.

Real time monitoring here and in space!

- Real-time monitoring in environment.
- … making sure that the monitoring stations on Mars (generating 80 databases an hour, checking for inadvertent release of yet more microbes) are feeding data to world.net live.
- Routine measurement of the stress level of whole ecosystems.

New innovations and technology giving new depth of data

…new techi innovations for the research community

- 'Star Trek Scanner' of organisms. Full molecular readout of genomic and functional genomic responses that inform directly on health of individual, population and ecosystem.
- Describe the status (health) and quality of any sample - based on a full range of physical, chemical and biological markers (assessment of potential resilience and risk).
- The expansion of technology to allow full coverage of the metabolome and proteome.
- The introduction of Next Generation Sequencing gave an extreme boost to science.
- Whole community – of all taxa - analysis of DNA – to sequencing depths where all the most dominant genomes are assembled and assays of the 'rare' biosphere plateau – even in microbes. (Complete sampling.)
- I can accurately profile the proteome/transcriptome/metabolome of a SINGLE CELL.
- High resolution at the demographic and selective history of populations at the whole genome level.
- Rapid, accurate identification of mixed environmental samples that covers quantity and quality.
- Study gene expression in non-model species.

….. Omics for everyone!

- I bought a 'soil genomics health' kit from B&Q – let's hope my marrows are bigger this year.
- My nephew sequenced the wasp genome, again! I wondered if he could attempt something more challenging.

….Omics increase sustainability

- Manipulate microbial communities to increase sustainability.
- Change agricultural practice to balance food production with a sustainable planet.
- What are the ecosystem goods and services provided by biodiversity?

….New Pharmaceuticals

- Biomining novel pharmaceuticals.

2 Exploring the context

2.1 What can Environmental Omics solutions do for:

2.1.1 Quality of life?

Thinking about the phrase

- This is a standard NERC requirement.
- Is it specifically human life or all life?
- Politicians want us to concentrate on human life.
- In grant writing we tend to talk about Quality of Life more in terms of understanding the environment.
- Contributing to UK culture – what is meant by this?

Help develop understanding about the role of biodiversity for quality of life

- Do we accept a direct link between Quality of Life and biodiversity? … by producing efficient methods we can.
- Question of: does biodiversity *per se* buffer require ecosystems against:
  - Natural resilience.
  - Prevent ecosystem collapse.
- Happiness (of people).
  - People get direct pleasure from knowing about biodiversity in their environment.
  - Proof or discovery of biodiversity.
  - Any kind of green space improves Quality of Life.
- There is evidence that where you live in a city can change life expectancy. Can we find out why?
  - What does an urban environment do to the humans in it?
  - Fish (as well as human).
  - Biodiversity in urban areas.
  - Invisible changes in biodiversity.

Detection and management of health risks

- Early detection of emerging pathogens or emerging resistance.

    - Can start in the environment and become a pathogen.
- Interaction between genomics of environment and host.
- Tool to help provide a link between cause and effect in, for example, disease – biological/chemical.
- Genetic susceptibility.
- Omics as a tool for chemical risk assessment
- We have already seen diagnostics in healthcare.
- Biomarkers.

New Medicines

- Natural medicines.
- Biomining for pharmaceuticals.

Understanding pollution & mediation of problems

- In Environmental Omics this is more to do with monitoring environmental pollutants and their impacts on the environment.
- Rapid environmental diagnostics.
    - For example, tools for pollution monitoring.
    - The key is prevention and early warning rather than cure.
    - Sensitivity of Omic detection techniques to sense pollution before it becomes critical.
- Discover of natural variation in tolerance to pollution/disease, for example heavy metal pollution.
- Bioremediation is possible (with, for example, plants) if previous is known.
- Provide new solutions to clean up and prevent pollution.
- By linking cause and effect you can predict the effect of any stressor or impact in an environment.
- That can be soil/water – same principles apply to human health.

Maintaining Ecosystem services

- Functional units and ecosystem services, for example physiological and chemical processes.
- Ecosystem services.

Understanding risks

- Monitoring gene response in humans in response to changes in their environment.
- Not just occupational.
- Predicting safety before new technologies are released into environment. Risk assessments.

Identifying microbes and genes that can work for us

- Identify microbes that can produce stuff we can use or degrade.
- Not necessary, just microbes. Even genes.
- We can find thousands of different variants and find the best for our uses. Clone it and make use.

Controlling pathogens

- In pathogens we see maintenance of genetic diversity even in the laboratory.
- In the laboratory wild-type C.elegans can be mutated to live twice as long. - But in the wild it dies out <27>.

Other comments

- More holistic/systems assessment, for example in area of human microbiome.
- Laboratory work is based on isolated simplified systems.
- Environmental Omic solutions reality-check laboratory findings and solutions.
- Novel pathway for biotechnology.
- Functional metagenomics.

2.1.2 Quality of environment?

Inform environmental management decisions

- Management decisions based on knowledge.
- We need to think about how Omics research can help us manage the environment, for example can if we can measure diversity at Omics level what does that add?
- Can detect an effect but what does it mean and how is the knowledge used – translation from research to use?
- Use in Environmental Impact Assessment.

- Provide infrastructure to make rapid assessment and decisions to influence policy-makers in the rapid timescales they work to, for example months not years (1).
- Rapid response so within a day information available to make better decisions. But challenges to bring this into operational use.
  - QA.
  - Q Control.

Effective communication needed to help decision makers

- This is only a solution if the policy-makers and managers understand the information - It needs to be delivered in an understandable way.
- This is also critical for support financially and policy backing to be able to deliver downstream benefits.

Predicting reducing and cleaning up pollution

- Predicting toxicity of environmental pollutants.
- Using genomics to guide risk assessment, for example for chemicals, building, any new disturbance. For example, identify sensitive organisms.
- Assessment of potency of compounds when they affect molecular level in organisms – and at what concentrations.
- Better clean-up.
- Effectiveness of the clean-up.
- New pharmaceutical products for medicine – they can be toxic in nature and damage the environment.
- Assessment of what mixtures of compounds do – cumulative or compound effects.
- Being able to direct clean-up efforts, for example oil spill in Gulf (1).

Understanding Ecosystems

- Providing tools for diagnosing environment issues:
  - For example, tipping points.
  - Soil/water quality.
  - Resilience.
- Understanding the impacts of specific contaminants on microbial community structure in relation to ecosystem services.
- Improve our understanding of impacts of different pressures on ecosystems.
- Delivery of ecosystem services.
- Linking cause and effect, for example disease, pollution, ecology, biodiversity.
- Make links between assessment and function.

Evolution & genetic adaptation

- Unravelling DNA to understand human origins and history of the earth, for example how populations have adapted to environment change in the past to adapt to what we are facing.
- Understanding Omics basis of phenotypic plasticity also for adaptation.
- Understanding rates and limits of adaptation.
- Catalogue genetic natural variation.
  - Biobank.
  - Storing DNA rather than informatics (such as the Millennium Seed Bank).
  - Can we provide information for future research – as we now can look at museum collections sharing diversity?
  - A resource for a thousand years!

Working with the environment and increasing resilience

- Working with the environment, for example agriculture, biofuels enhanced ability to work with the environment.
- Increasing the resilience of the environment, preparing for unfavourable events, mitigating effects, for example ocean acidity or temperature increases.
-
- Identifying genetic solutions to man-made problems.
  - For example, the energy crisis.
  - For example, Craig Venter's work on marine algae for petroleum production or novel pharmaceuticals such as natural medicines from nature.
- Understanding biogeochemical cycling in relationship to greenhouse gases emissions and regulations.

Ecosystems & biodiversity

- Conservation of biodiversity.
  - Details of genetic structure.
  - Goes deeper than species.
- Understanding what to conserve.
- Understand genetic structure of whole ecosystem.
- Quick, cheap, high quality assessment of biodiversity and therefore quality of the environment.
- Early detection of invasive species before they become established.

Use Omics to reduce the use of experimental animals

- Provide validated predictive tools to reduce use of experimental animals.
  - Disease work.
  - Environmental chemical management.

2.1.3 Sustainable living?

Question: Sustainability of human <u>or</u> sustainable living for <u>who</u>. Need to define and clarify the question better. Sustainability a much bigger question. "How can Omics deliver information to help measure ecosystem sustainability and viability?" (Humans included but not <u>only</u> humans.)

Food & agriculture related

- Describing the genetics of non-domesticated animals, allowing better agricultural species.
- Food security, working with other partners such as BBSRC.
- To develop new interventions that have a lower impact on the environment, for example development of fertilizers, antibiotics.
- Understanding the true (or otherwise) effect of genetically modified organisms on the environment.

Climate change & energy

- Monitoring effects of climatic change in the living world.
- Biofuels/Bioenergy, for example identifying optimal alternative energy sources (2).
- (2) Bioenergy, for example using microbes to generate energy.
- Biofuels – need to exploit the marine environment more. 70% of environmental marine. Terrestrial crops can not sustain current demands for food and fuel.

Conserving biodiversity & ecosystems

- To assess biodiversity loss.
- Understanding adaptation at range margins.
  - Capacity to adapt to environmental change (genetic plasticity).
- Understanding biodiversity at range margins.
  - How communities change.
- Preserving biodiversity to allow discovery in the future, for example seed banks.
- Tracing the origin of biological material, for example the illegal logging of controlled species.
- Understanding genetic basis of species interacting and therefore the sustainability of ecological communities. "Community genetics".
- Isolating genomic modules underlying adaptations to specific environmental challenges.

Understanding natural processes. cycles and tipping points

- Better understanding of geo-biochemical cycles and realistic models
- Getting biology/ecology into models, for example climate change, biogeochemical cycling (physical and biological scale).
- Identifying 'tipping points' (what causes a system to change irreversibly – a tipping point that causes a change in state of a system).

Landscape scale functions and genetics

- Making better informed land use options, for example identifying functional constraints on landscape genetics for sustainable delivery of ecosystem services. Understanding the genetics on land may inform the use.
- Characterising landscape genomics – using genomic information to help town planning, etc.
- Encouraging combination of information about non-living and Omic information on global scale so load can be shared to encourage sustainability at a global level.

Environmental health links with Human health

- Assessing interactions between environmental microflora and human microflora (with regard to

antibiotic resistance).
- Through understanding of environmental species genetics, develop better methods for sustainable manufacturing of drugs and chemicals, etc.
- Using genomics to measure environmental health. Formulating an environmental health index for policy-makers.
- Promoting health, protective screening and changing lifestyle.
  - Tackling causes rather than treating effects.

Monitoring remediation
- Using Omics to determine if remediation has been effective.
  - Use in monitoring generally.

Checking the safety of new technologies
- Ensuring the safety of new technologies, risk assessment, for example nanoparticles and affects on organisms' physiology measured by gene expression, molecular responses. Any number of metabolite changes. Any number of changes in abundance.

Translate research into real impact
- Need to translate the research results into real-world impact.

2.2 Opportunities, challenges and trends for Omics research

2.2.1 Challenges for Omics research

Thinking about what may need strategic investment - what challenges are there for doing Omics research? (Eg Technical, bioinformatics or data management)

Data management and handling
- Data Tsunami.
- Too much data to analyse with current infrastructure.
  - Human Resources.
  - Bioinformatics.
  - Cultural problems.
- Avoiding unnecessary data collection – collecting data for the sake of it.
- Sufficient collection of meta-data to allow reuse.
- Data may not be fully exploited.
- Turning data into functional information.
- Standardization of data and formats.
- Outsourcing data and samples – problems with cross-county outsourcing.
- Data integration.
- Integration of numerous Omic data.
- Parallel sampling on a massive scale in time and space.
  - For example 1000 Genomes Project.
  - Need breadth.
- Scale of problem is huge.
- Funding projects based on available data.
  - Computer-based research only for example.
- Learning how to model. Process.

Access to data for the research community
- Meta-data (for open access).
  - Recording data.
  - Standardization (at metabolite level).
- Meta-data required for publication.
- Pilot Studies and knowing people to go to for/with data.
- Access to data (commercial).

Access to data for everyone

- Access for the proletariat
    - Access for the little man.
    - Lowering the bar.
    - People with ‘crazy’ ideas.
    - Pilot Studies.
- Public access to data.
    - Open access.
    - More can be done on one set of data.

Bioinformatics

- Involvement of bioinformatics/statistics in experimental planning.
- Getting access to good informaticians.
- Archiving for re-use and meta-analysis.

Omics breadth, collaboration

- Genomes is not answer to everything - Numerous Omics technologies and methods
- Learn from other areas, for example systems biology and others.
- Interact closer with other areas, for example the medical field.
- Need to attract people from other areas.
- To develop a different culture – to model more inter disciplinary work.
- Absolutely promote collaboration with, for example, the USA.

Training and educating other key players

- How to keep up to date for training next-generation researchers.
- Educating peer reviewers on process of data-driven science.
- Difficulties in technical communication.

Need to look at the big picture

- Need to look at bigger picture.
- More strategic focus on ‘big’ issues – for funding research.
- Meta analysis.

Identifying research priorities

- How to ask questions.
- Focus on specific areas.
- Being selective and supporting projects adequately.
    - A little bit of everything.
- Environment is not ‘sexy’ like healthcare and medicine.
- Diversity of environment.
- Vertebrate bias.
    - More people working on tiny proportion of life.
- How do you know what the question is?
    - Prioritization.
    - What do I do?

Don’t reinvent wheels

- Don’t reinvent wheel on translational Omics.
    - Tapping available resources.
    - Teach us from mistakes.
    - Give us advice.
    - Adopt the good bits

Resources & technology

- Integrating resources.
- Development of methodologies bioinformatics methods.
- Facilities that make it easy/offer multiple integrated Omics. - May not want multiple facilities for different Omics.
- What is the best technology/provider, and how best to approach a problem.
    - Community best practice.
- Decisions on waiting for new technology.

Being relevant and current

- Matching technology to environmental issues.
- Keeping technology current.

Funding

- Being clear about link between large funding and the impact on environment.
- Knowing how funders relate to one another.
- Sustained funding.
- Money.
- Cross-research Council funding.
- Lack of funding (long-term).
- Academic/industry partnerships.

Closing gene function gap

- Closing gene function gap from data generation.

2.2.2 What opportunities are there for doing Omics research?

Thinking about what may need strategic investment - what opportunities are there for doing Omics research? (Eg Technical, bioinformatics or data management)

New opportunities in the way research is done

Technological

- Technological capability facilitating advances that were not previously possible.
- If they still are only providing partial answers when is the right time to start?

Capacity to handle data

- Computing infrastructure mainly towards broad sharing of very large data sets.
- Data handling, data processing bioinformatics.
- Exploit existing sample and data-sets.

Big questions are easier to tackle

- Big questions can now be asked by a single laboratory.
- The ability to do MEGA Projects high-throughput, 1,000 Genomes at a time.
- One million species, partial genomes, DNA barcoding for tagging species and monitoring.

Knowledge exchange and cooperation

- International cooperation, at the level of funding, infrastructure strategies and technology.
- Opportunities to learn from other RC's Omic facilities, for example lipidomics at MRC Cambridgeshire and metabolomics at BBSRC Rothamsted. NBAF needs to have cross-talk and share experiences.
- Knowledge exchange with environmental industries and policy-makers.

Continued investment

- Continued investment in facilities, for example NBAF.
- Continued funding that NERC sustains.

Prediction and monitoring

- Prediction of the effects of change on the environment.
- Monitoring networks long-term spatial, temporal.
- Support for long-term data sets.
- Fitting in these technologies into existing environmental monitoring schemes (government as well as research) or on-site. Use of remote or on-site sensing to measure Omics processes in remote or extreme environments. The opportunity to link into real-life issues.
- Climate change modelling through ice core sampling.

Omics research disseminated and democratised

- The democratization of Omic research.
- Training and dissemination of knowledge.
- How to build capacity within the decision-making community, in using Omic data in environmental policy and management.
- Addressing the policy vacuum.

Suggestion:

- Develop a cross-Council team to facilitate joint projects and interaction, for example human health and the environment.
- Combining Omics with expeditionary investigation, cruises, submarines.

New and developing fields of research

Opportunities
- Opportunities to develop new theoretical or conceptual approaches.
- Solution-focussed rather than problem-focussed. Understand the problems and provide solutions.

Research Ideas:
- Development of Biostatistical/Bioinformation methods specifically addressing generic environmental problems. Sparsely unmutated organisms, in uncontrolled conditions.
- Providing validated tools for animal reduction/welfare in drug chemical development, toxicology assessment, environmental toxicology.
- More understanding of genetically modified organisms and how they affect the environment, safely exploiting genetic modifications while avoiding deleterious or adverse consequences for the environment.
- Linking and integrating Omic data with other types of environmental data.
- Closing the functional knowledge gap between sequence data – 40% of sequence unknown.
- Robotics! Integration of genomics tools into robotics.

Epigenetics
- Environment, epigenetic interactions.
- Knowledge of natural epigenetic variation.
- Population epigenomics.
- What is the basis of phenotypic plasticity?

Biodiversity & Ecology
- Build an existing long-term ecological studies centre.
- Really efficient, rapid biodiversity assessment tools.
- Linking ecological structure to function.
- Conservation biology – identifying vulnerable species, genetically vulnerable species.
- 'Biobank' – akin to the Millennium Seed Bank, containing/preserving DNA, a catalogue of Natural Variation.
- Understanding species diversity impact on human health, for example fungal species in asthma. And the effect of human activity on diversity.

2.2.3 What do we need, to do good Environmental Omics research?

Thinking about what may need strategic investment - what do we need to do good Environmental Omics research? (Eg Technological, bioinformatics or data management)

Know the question and drivers
- What is the question?
- What should drive the science?
  - Tools <u>and/or</u> questions?
- What drives the research?
- Science questions to drive technology.
  - Hypothesis generating?
- Theoretical framework to aid interpretation of environmental interests.

Integrated approaches
- Integrated use of multiple types of Omics (Omni-omics!)
  - Data fusion/integration (tools for these).
- Systems-based approach.
- Learning from other fields.
- Encourage multi-faceted teams … or not?

Expanding research fields
- Expansion of Omics fields.
  - (Epigenomics.)
  - (Proteomics.)

Education & CPD
- Education (MRes) – targeted.
- Ongoing professional development/education.

- Summer school for multi-level training, for example Washington University Summer School in Statistical Genetics.
  - Modular.
  - Summer School/short course.
- Improving mathematical skill.

Funding & Resourcing

- Funding to access technology.
- Cost?
  - Cheapness.
  - Lower price <u>or</u> price per sample?
  - Investment in facility.
  - Subsidy?
  - Time/set-up.
- Facilities/personnel in every laboratory.
- Dedicated computer facilities.
- Trained people for these.
- Cross-Council/funders of projects.
- Scientific community to determine funding (power at the base).
  - Funding ‘risky’ science.
  - Funding ‘people’, not research?

Improved Internal & External Communications

- Specialist A ←→Specialist B, and support.
- Recognition of Omics/team members.
- Encourage - force! - a culture of data-sharing.
- Appreciation/awareness in peer review panels.
- How to sell Omics.
- Closer links with stakeholders.
  - Industry.
  - Policy-makers.
  - NGOs.

3 Developing ideas about innovative and high impact Environmental Omics research

3.1 What are the big picture research questions the community would like to address?

Ecosystem function and systems

- What ecosystem services are delivered by biodiversity?
- How and where ecology matter, at individual, community and landscape.
- What is the variability?
- Contribution to the development of a systems biology approach.
- Scaling up from gene to ecosystem in any habitat, over any time.
- For example, inter-seasonal, inter-annual).
- Need for big unifying questions.
- Improve ability to parameterize the natural environment.
- Understand which model is appropriate in what setting.
- Models based on good environmental data.
- A predictive tool, hypothesis-building to formalize understanding of the system.
- How do environmental communities assemble over evolutionary time and space?
- Can we compute bioproductivity by Omics? Number of genomes in an ecosystem.
  - What is in those genomes?
- Use to predict effective interventions, productivity, resilience to change.
- What is the minimum information required to predict?
- How will a less diverse world be sustainable?
- Landscape genomics – understanding how mankind influences genetic isolation and impacts on biodiversity.
- Understanding systems as a whole.
- Conversion of atmospheric N_2 – enzyme mediation rather than the organisms mediating this.
- Biosphere/geosphere interactions and earth system cycles, for example N_2O_2+C.
- Amount of N_2 in the environment rather than in the organism.
- Cellular level communication to policy-makers.
- Assessing whole systems in one go, rather than separate like biodiversity.
- Identification of stresses within compartments.
- What is the ecological significance of molecular variation?

Human activities & environmental health

- What are the connections between the organisms in an environment – community structure? How do humans influence these connections?
- How do human activities affect environmental health?
- Understanding the long-term effects of pollution (pollution – human, anything where it shouldn't be – for example arsenic concentrations in the soil, could be from environment, from a smelter, ground water).
- What will the long-term effects of pollution be? Can we ameliorate environmental damage?
- Diagnosis of environmental problems from molecular data?
- Understanding of mechanisms of action of, for example, chemicals?
- How do we integrate Omics into risk assessments and hazard identification?
- Pollution impact on cellular organism.
- What is the interaction between the epigenome and the environment?
  - For example minimizing risks of chemicals on mutation.
  - Effect of UV light on genetic behaviour.
- What are the mechanisms driving/controlling microbial diversity and its effect on ecosystem function?
  - Ecosystem function including biogeochemical cycling.
- Using Omics technologies to measure ecosystem health.
  - Diversity, function, richness biotic indicator species.
  - Reanalysis of the relationship between above factors and man-made impacts/activities.

Enabling science in developing world
- Enabling biodiversity science in third world.
- Extinction – can anything 'go extinct' if you know all the genes?

What is normal and what is unique
- Defining what is 'normal' range both in communities and individuals to detect deviations from the norm?
- Characterizing the rare or unique?
- Ecosystems assessment using the Omics technologies.

Climate change & environmental effects
- Climate change and effects.
  - Predictions for environment
  - Including human induced.
  - Natural change.
  - Pollution.
  - Global warming.
- The ability to assess and predict the impact of environmental change.
- In 10000 years what will have been the effect of climate change?
- What will the effect of climate change be?

New energy sources
- Is transition to a post-oil economy possible?
- Finding alternative energy sources.

Food future
- Food productivity versus ecosystem services.
- What is the carrying capacity of the world? When will we run out of food?

Human health & medicine
- Human health.
  - Too much focus?
  - Environmental impact on …
- How does what's there impact on human health?
- Identifying 'useful' genes, organisms, molecules.
- Identifying surrogate species for humans to advance drug development.
- Systems re medicine relating structions and functions.

Origins and genes
- Origins of species – at molecular level.
- Do speciation genes exist?
- Can't ignore viruses.
- Interaction between species at molecular level.
- Origins of life.
  - Barcoding to identify everything.
- Eco structure composition.
  - New species identification tool.
  - DNA system.
- Creating a Biobank of DNA for the future. Digital or physical?
- Direct information flow.
- Historical flow of genome information out – both directions.

Diversity
- Understanding biodiversity.
- (1) Variation within species?
- How variable are individuals within a species (in the context of time and space)?
- How many taxa are there?
- What is the variation within a species?
- Biodiversity – what's actually there?
- How much turnover is there on the planet?
- How many species are there?
  - Quantifying biodiversity.
- Measuring total unbiased biodiversity in systems.
- Information summary re diversity and state.
- Using Omic technology to characterize biodiversity. - What are the data gaps? - What are the

mechanisms of action, input and effect of response? Chemicals and interaction.
- Unbiased gene expression profiling.
- Biodiversity.
  - What does, for example, colour mean?
  - Evolution genetic basis.
  - Gene pool.

Global gene pool
- How big is the 'gene pool' – global/meta?
- Global proteome and metabolome. -
- How much does 'it' all matter?
  - To what extent are they reliant?
- Opportunities for meta-genomics.
- (1) Do we know what the key ecological species are in order to make decisions?

Adaptation
- Parameters change but community functioning remain stable.
  - Adaptation to environmental conditions.
- To what extent does ecosystem stability depend on biodiversity?
  - Cycling and feedback.
- Rates of evolutionary change.
  - Changes/ limits to adaptation.
  - What control ranges?
- What is the genotypic/phenotypic basis of fitness (both evolutionary and individual)?
- Genomic basis of adaptation.

- How do organisms adapt to the environment?

Environment and Gene Interactions
- Environment to gene and gene to environment (epigenetic).
- Understanding gene/environment interaction.
- Gene taking its information from the environment.
- Environment challenging the genome.
- Epigenetic modification sub-cellular levels.
- Epigenetics important re how the environment affects the genome.
- How does it affect the organism?
- Molecular levels of interactions.
- Role of metabolomic complexity re the environment. Secondary metabolites of plants re pathogens, etc, superstructure within the plant.
- Whole organisms and specific processes within the organism.

Other
- Annotating metabolomes of key ecological species.
- Isolation of proteomic level.
- Self-perpetuating complexity – secondary compounds versus matrix (isolation).
- Synthetic biology.
  - Event horizon.
  - Bioremediation.
- How can we make best use of all the data we gather – need to develop bioinformatics?
- **OR** How can bioinformatics be developed to make best use of the data, for example relationship to meta-data?

3.2 What challenges are there that Omics could help solve?

Ensuring what we do is affordable and makes a difference to the big global issues
- What we do has to be cheap/affordable.
  - In this for a Westerner's feel-good factor or is there real impact?
  - For example, antibiotic resistance is a global problem.
  - New ideas for more sustainable living in Third World.
- Open access needed. Poorer countries can contribute via computation if they have open access.

- Big challenges addressed :
  - Energy.
  - Food security.
  - CO_2.
  - Impact of biofuels on environment.
  - Population → Disease.
  - Impact on managing zoonoses and emerging diseases.

Creating a DNA-arium sequencing bank

- Creating a DNA-arium.
- Documenting biodiversity – certainly – thus biodiversity change and functional consequences.

Baselining biodiversity

- Deep sequencing of phylogenetically interesting species.
- Biodiversity across scales.
- Baselining the diversity of natural systems.
- Is a 'tricorder' (DNA barcoder) system feasible?
- Defining the true extent of diversity intra-species and community.
- Understanding the importance of diversity and roles played.

Origins of Life

- If we can find everything that is around now we can work back to deduce origin.
- Man is easier.
- What about the origins of life and extinction?

Adaptation

- Monitor evolution and adaptation in action, for example in test tubes, seeing feedback responses of environmental change.
- Genetics and adaptation. Pheno plasticity.
- Find clade–defining genetic changes.
- Helping understanding 'fitness' and organism adaptation to environments.
- Understanding the cost of fitness.
- How organisms can/can't adapt – the mechanisms and the limits and costs of that adaptation.
- How have communities responded to past climate change?
  - Bring in modellers to make predictions.
  - Test model.
  - There is a lot of environmental data already to put into this.
- Predicting using analysis of ancient changes (for example climate) to inform models of present phenomenon.
  - Genomic changes as a result of environmental treatments (for example fertilizers and drugs).

Creating new life or recreating lost species

- Can we create life?
- Can we recreate historic environments, resurrect ancient organisms?
- When we 'terraform' another plant, what should we include?
- Can we create synthetic organisms to bio remediate?

Carbon sequestration

- Carbon sequestration.

Cell modelling

- Making a comprehensive virtual cell model – computer program.
- More model systems – make non-models into models.
- Find useful models rather than convenient models.

Environmental monitoring, management & sustainability

- Molecular biomarkers of climate change.
- Mitigation or monitoring.
- Can we manipulate the environment on a large scale?
- Accurate impact assessment of environmental quality.
- Living truly sustainably within the systems.
- Site understanding re where the impacts really are.
- Discovering principles of mechanisms, for example ocean acidification.
- Toxicity of nanoparticles.
- Genomics can help deliver on monitoring ecosystem health.
- Mitigation of and protection from the effects of environmental change/damage.

Better biodiversity conservation

- Making biodiversity conservation better targeted and more cost-effective.
- Conserving and knowing what to conserve re genetic diversity.
- Improving international cooperation on the above.
- Linking research to applications or management, for example barriers (man-made) to gene flow, and ref Bangor University work on hedgehogs.

Human health & disease

- Impact on managing zoonoses and emerging diseases.
- Can we predict where the next zoonoses are going to come from?
- Understanding the effect of the environment on health.
- Discovering new drugs.
- Can Omics reduce the need for animal research?
- Help extrapolation of data to humans in risk assessment and disease effects.
- Understanding of strain and species responses; using Omics will assist in understanding differential human susceptibility to drugs and chemicals and mixtures thereof.
- Understanding the role of background environment on human health, not just microbes but water quality, etc too.
- Finding new pharmaceuticals from new genes in the environment.

Advantages of Omics methods

- Ecosystem resilience, Omics avoids sample bias.
- Shifts the paradigm away from a complete understanding of what's going on.
- Understanding complexity and uncertainty.
- Can look at a lot of organisms very quickly.
- Added value of persistent data resources that can then be used as robust diagnostics.
- Modelling complex systems and being able to predict how changes could affect them.
- The development of novel modelling approaches.
- Gives us the ability to study non-culturable organisms (in depth).
- It will help fill the gap between sequence data and functional knowledge.
- It will lead to broad or phylogenetic range of organisms studied.
- It will help to overturn the historical over-type of Omics and regain credibility and be realistic.
- Real-time assessment and ability to do massive parallel sampling with high temporal and spatial resolution.
- Omics data impact will be huge on modelling data – like a feedback – linking to systems.
- Model importance for management.
- Efficiency and sensitivity of biomarker approaches.

3.3 How can Omics change the way we manage the environment?

Monitoring

- More efficient biomarkers.
    - More sensitive.
    - More accurate information allowing for informed decisions.
- Accurate monitoring of environment.
- Improving focus of monitoring to better targeting.
- Characterizing baselines – basic systems as foundations from which to build.
- A tool to monitor the quality and efficacy of any intervention, including interim measures of success/failure.

Biodiversity

- Don't know where biodiversity is.
- Omic diversity.
- Describing communities and biodiversity.
- Difference between habitats/environmental.
- Preventing "genetic erosion" (for example in-breeding or losing variation) within species.
    - Closeness of individuals (genetically) and viability of future generations.
- Genomics can tell us where pockets of isolation exist and inform strategies to help reduce this isolation.

Provision of good quality data and evidence

- Provision of relevant data.

- Provision of meta-data linking Omic data to environmental data.
- Only if we understand the normal operating ranges, what is the standard?
- Identification of key-indicators.
- Identification of regions/areas of importance.
- Help to focus effort on prioritizing areas (time and funding).
- Rarely a single issue under investigation; power of Omics would allow the bigger picture to be investigated.
- Breadth and depth of sampling with effective resourcing.
- Helping improve repeatability for better data robustness.
- Reducing assessment factors for improved standards.
- Improving quality of evidence.
- More power to assess for quality of scientific case for policy.

Systems Assessments

- Systems assessments and subsequent decisions to reduce/eliminate bias re key species and increase accuracy and quality control.
- Whole community understanding of systems.
- What is a 'basic system' – all are complex and stressed – will grow up to level of tolerance/resilience.

Risk Assessment

- Enabling more mechanism-based risk assessment across species.

Understanding environmental change

- Determining susceptibility of organisms to environment.
  - Which organisms and which environment.
- Predicting changes rather than reacting to changes.
- Understanding of ecosystem tipping points.
- Understanding resilience tipping points.
- Understanding historic rate of change – on environment, traits of organisms, diversity of organisms.
- Genome – long-term changes, other parameters – shorter term (overview gives the scale).

Environmental management and food production

- Help support conservation management, for examples populations susceptible to ….
- Pre-screening of sites of environmental concern.
- Help in identifying issues of concern (through introduction into monitoring).
- Can't manage the environment if we don't know what is in it.
  - Unknown unknowns.
  - Threatened environments.
- Current methods of management.
  - Agriculture.
  - Waste water.
  - Flood defence.
  - Housing.
  - Provision of food.
  - 'Food security' (don't like phrase).
  - Reverse globalization.
- Self sufficiency leads to improved local biodiversity.
- Better prediction of food production, conservation and restoration.
- Improving agricultural sustainability and productivity.
- Changing sugar content of grass in dairy pasture management to lower CH_4 output from cows.

Environmental damage & remediation

- Measuring environmental footprints.
  - Environmental responsibility.
  - Informing public.
- Recovery of environment.
  - For example mining/quarrying.
  - Oil spills.
  - Actively aiding recovery.
  - Getting involved in specific cases.

- Bioremediation.
- Remediation of undrinkable water.
- Detecting pollution.
- Assess the success of restoration/remediation.
- Help define ‘good ecological status’.
- Risk assessments prior to release into the environment.
- Predictive tools for chemical and environmental impacts, for example ‘virtual fish’.
- Identify cause and effect relationships.
- Pest management strategies.
- Classifying stresses to the environment, for example chemicals.
- Risk re chemicals based on only a few species and extrapolated so expanding knowledge.
- Omics will provide an opportunity to alter how chemicals are assessed, for example biodegradation analysis – much more complexity re impacts.
- Mixes of chemicals compared with individual chemicals – big impact.
- Can characterize the impact of chemicals on ecosystem.
- Challenge is the mechanism and how it can impact on all organisms. Prevent release of toxic mixtures into the environment.

Genetic modification

- Genetic engineering.
  - Convincing the Public.
  - Price of fuel.
  - Higher prices will be a driver for public acceptance.
- Understand the effect of genetic modification on broad gene expression relative to the nature species and impact on natural environment.

Political decision making

- Would improve accountability (tracking, monitoring ability) of individuals and governments.
- Improve information on which to base decisions. Increase speed of information.
- Create an environmentally more aware electorate and government.

3.4 What is the most cutting edge, innovative, synergistic ideas you can come up with to advance environmental understanding?

Please note this was done as a brainstorm, so creative, unusual and even crazy ideas can be suggested without any explanation or justification

Cutting edge and innovative Ideas

Omics Gizmos

- Barcode reader ‘tricorder’ gadget – instant identification.
- Portable genomics (tricorder).
- Tricorder.
- ‘Minority Report’ environment for experimentation.
  - Nintendo Wii.
- Omics on the Wii.
- Beyond super-computing.
- Biocomputer.

Omics in the garden, field, Tesco’s and schools!

- ‘Garden-Omics’.
- Gardenomics.
- Field Omics.
- Tesco’s genomics service.
- Free DNA barcoder for every child.
- Omics in schools.
- GCSE in molecular biology.
- GCSE projects – sequencing genomes.

Omics for all

- Give everyone access.
- Omics as mainstream.
- Engaging the Public.
- Omics in/and the developing world.
- Omics on line – public engagement.
- Personal bioinformaticians.

Remote Sensing

- Remote sensing of Omics.
- Links between satellite imaging and Omic.

Omic Expeditions

- Omic expeditions.

Ecological systeomics - systems thinking

- Ecological systomics.
- Landscape level interaction with ecosystem services.
- Omic prediction of ecosystem function.
- Multi-dimensional interpretation of Biodiversity Dynamics.

Omics in the field

- Taking laboratory into environment.
- Field-based genomics.

New Humans

- Transgenic humans.

Humans finding ways to photosynthesis

- Personal photosynthesis.
- Photosynthetic clothes.

New bugs and the atmosphere

- Creative new bug to capture CO_2 to $CaCO_3$.
- The 'perfect bug'/metabolically loose. - Crude cell.
- Make CO_2 into $CaCO_2$.
- Bugs to live in atmosphere to adjust cloud formation.
- Clean-up bug starts with generic function and is evolved to be more effective.
- Can we control DMS in the atmosphere?
- Biosphere-geosphere interaction.
- Re climate change.

Life

- Fundamentals of life.
- To sustain life.
- Seas to sustain life.
- Immortality.
- Peace and love, understanding.
- Understanding sex.

Sequence everything …

- Sequence everything.
- Global survey of metagenomic – sea/soil.
- Sequencing tree of life.
- Tropics to the Poles, to the deep sea.
- Reconstruct the original ancestor to all life.
- Find all genes.
- Knowledge of the emin-ome genes ⇄ protein ⇄ metabolite → phenotype Omics
- Store the DNA.
- Barcode everything.
- Find all potential genes.
- Pick out individuals in individual cells, for example sea.
- What knowledge we have in the data we've got.
- Global metaproteomic and metamelabolomic surveys.
- Genotypes pc to Phenotypes pc - and everything in between.
- Sequence 'Ome' genome of everything bigger than 5mm.

- Species level genomics.
- Species level Omics – integrate Omics.
- Metagenome of UK (every km) metagenomic map.
- Ancient biomolecules of museum specimens.
- Planet's genome.
- Global DNA Biobank.
- Functional meta-genomic screens.
- Uniform curation and annotation.
- Full molecular phylogeny.
- No functional data gaps.
- Quantifying all Omics levels/hierarchies.

…. And understand what it means

- Gene networks.Regulation/function.

- Variability and resilience.
- Basic laws of biodiversity.
- Universal way of looking at diversity patterns.
- Single measure of biodiversity.
  - Biodiversity index.
  - Measured in a universal way.
- Genomic variation and adaptive importance.
- Cell transcriptions.

Real time monitoring

- Real-time whole ecosystem observatory.
- Real-time monitoring.
- Real-time meta-genomics.

Ecosystem Assessment

- In line ecosystem Quality Assessment.
- Quantifying environmental impact of human activity.

Environment sampling and baselines

- Understanding base-line.
- Complete sampling.

New Food - new fuels

- New crops that will feed everyone.
- Can we make the perfect crop?
- For food or fuel or both?
- Got to find phenotype in-between is interesting stuff.
- Marine or terrestrial?
- Food supply.
- Energy solution.

Clean Water

- Clean water.

Predictive science

- Predicting novel compound impacts.
- Predicting toxicology.
- Predictive science.
- Predicting evolutionary outcome.

Omics in space

- Finding DNA-based life on Mars correlating species diversity and genetic diversity.

Doing Omics Research Better

Staying creative

- Interdisciplinary think-tanks.
- Secondments of different disciplines cross-boundary.
- Genomic Tsars.

Cross disciplines

- Integrating enviroscience with social issues and economics.
- Changing organisational interactions.

Better data

- Through-put rapidity.
- Free sequencing.
- More spatial and temporal data and biological material.
- Seamless data integration.
- Less Omics terms.
- Better functional annotation.
- Quality control of Omics data.
- Small (spatial) scale Omics.
- Lower cost for sequencing.
- Biologically interested bioinformaticians.

New IT

- Cloud computing resources for computing/analysing Omic data.
- Virtual reality for looking at data.
- Computing biology from Omics.
- Virtual organising.
- Efficient programs/models/computers.
- Fully automated data analysis.

Open Access to data

- Open access to data (everyone's).
- Anyone can get into the data.
- Full and open data sharing.
- Information access.
- No restrictions to using genomic data.
- Quality free-ware for data analysis.

Funding

- Unlimited funding.
- Real – high – throughput.
- Infinite funding.
- Cross-Council projects.
- Life-time funding.
- Way of assigning credit.

Government policy

- Omics and Government policy.

Skills

- Skills for design.

Unsorted

- Public annotation programming.
- Resurrect the Burgess Scale.
- Final Game.
- Artificial intelligence.
- Predictive eco-toxicology.
- Genomic time series.
- Own infrastructure.
- RIVPACS on a chip.
- Flow-through species identification.

- Functional trait identification.
- Fitness qualification.
- Quantifying whole organism responses.
- Genome interactions between organisms.
- Quantifying gene flow.
- Assigning novel [2y] metabolites.
- Extreme environments, for example characterizing.
- Proteomics that work.
- Theoromics.
- Full Metabolomic library.
- Genomics as quality control.
- Better understanding of platform limitations.
- Synthetic ecology.
- Identity card scheme.
- Single measure of environmental VALUE.

3.5 Out of everything, you have heard and discussed over the last two days what are the two ideas that you would most like to see research focus on?

Top four priorities

Ideas	Sticky dots for the cluster	Total
Understanding Fitness and Species Adaptation	**11111 11111 11111**	**15**
Ecosystems – systems thinking - understanding and limits	**11111 11111 1111**	**14**
Global 'Hidden' Biodiversity	**11111 11111 1111**	**14**
Climate Change Effects	**11111 11111**	**10**

Post its and prioritisation exercise

Ideas	Sticky dots for the cluster	Total
Omics for all! (Including Joe Bloggs)		
Public Engagement	**1111**	**4**
– Public engagement in Omics.		
– Reconnecting humans and human society to the environment rather than barricading them against it.		
Smart Cheap Gadgets	**1111**	**4**
– Rapid, hand-held, cheap Omic analysis equipment for assessment of ecosystem function.		
– Simple efficient cheap device to assess ecosystem composition in the field – using barcoding.		
Every School Knowing its Environment and Biodiversity DNA	**111**	**3**
– A DNA sequence in every school – NERC shows the UK to know its environment and biodiversity.		
Easy Access to Data for Non-Experts	**1111**	**1**
– Universal easy access to data in a format non-experts can understand.		
Impacts		
Climate Change Effects	**11111 11111**	**10**
– Study current response of organisms/biodiversity to climate change. Sensitivity? Plasticity?		
– Adaptation to climate change.		
– Global multi-Omics survey of sea/soil for monitoring of climate change effects.		
Toxicity	**11111 111**	**8**
– Genomic Tsars for modelling pollutant impact on whole ecosystem.		

Ideas	Sticky dots for the cluster	Total
– Revolutionize our understanding of chemical toxicity.		
– Tracing (bacterial) genes with special functions across environment to identify hot-spots for chemical stress.		
– Understanding 'normal' variation for toxicology and ecotoxicology.		
Monitoring and Modelling	**1111**	**4**
– Applications of Omics to biodiversity monitoring and modelling.		
Impact and Prediction	**111**	**3**
– Ability to predict impact of environmental change on an ecosystem both rapid change (for example pollination) or long-term (climate change).		
– Prediction of outcome for organisms of environmental stresses.		
– Understanding complex stressor impacts on the genome.		
Real-time multi dimensional analysis of biosphere	**11**	**2**
– Real-time multi dimensional analysis of the biosphere.		
Using Key Species as Indicators	**11**	**2**
– Complete knowledge base of inputs at the Omic level linked to defined pressure or key environmental species.		
New Knowledge		
Understanding Fitness and Species Adaptation	**11111 11111 11111**	**15**
– Understanding fitness and adaptation at the level of the genome (individual and community).		
– Determine the Omic basis of adaptation and species formation.		
– Genome-wide understanding of adaptive response.		
Understanding Past Ecosystems – for Future Choices	**11111 111**	**8**
– Analysis and integration of genomic and other levels to understand the past and model the future processes.		
– Ice core metagenomics.		
– Genomes through time using soil cores.		
– Recreating a complete past ecosystem.		
– Exploit ancient biomolecule studies to inform approaches to studying environment.		
Pristine Environments		**0**
– Identify the most 'pristine' environment in the UK.		
Logging Biodiversity		
Global 'Hidden' Biodiversity	**11111 11111 1111**	**14**
– A universal biodiversity constant/measure. Assessing diversity in uniform way across the world.		
– Fast, high-quality determination of biodiversity and species identification.		
– The complete genome of <u>all</u> temperate organisms – 'bedrock to treetops'. 'Biogenome inventory'. The building blocks of life.		
– Investigation of hidden biodiversity – 2^{nd} generation and phyloinformatics and metagenomics.		
– Biodiversity and monitoring.		
– How much variation within a species?		
– Determining gene functions for 'orphan' responders.		
– Single copy genomics, for example one DNA molecule →whole genome.		
DNA-arium, Biobanking	**11111**	**5**
– Total ecosystems biological diversity documentation/monitoring.		
– Determine and catalogue the earth's biodiversity – create a global 'biobank' – 'DNArium'.		

Ideas	Sticky dots for the cluster	Total
– Catalogue of all life (a mix of DNA barcodes and 100,000 genomes. – Linking environmental sampling to species names/existing knowledge and genomes.		
Origin of Life	**11**	**2**
– The Origin of Life.		
Ecosystems		
Ecosystems – systems thinking - understanding and limits	**11111 11111 1111**	**14**
– Understanding complexity genes to ecosystems in any habitat. – Ecosystem services and potential future uses. – (1) Spatio temporal maps of the global/regional/national/local meta(gen)omics. – (2) Complex systems: linking structure to function. – Omics and ecosystem health/services. – Informed ecosystem design and construction for beneficial ecosystem function. – Rapid metagenomics of whole ecosystems; assessment of stakes, detection of trends. – Exploring the limits of the biosphere: biosphere-geosphere interactions. – Whole system Omic level understanding of processes and links with fitness. – A Metagenome analytical platform that delivers functional ID, phylogenetic affinity, cellular compartment and thus community systems biology. – Define variability and resilience in ecosystems. – Assessing/monitoring ecosystem function and fitness using 'systems science' (multi-Omics) approach of organisms. – Develop a new mathematical framework to model living systems. – Comprehending multi-directional gene ↔ protein ↔ metabolite ↔ whole organism ↔ environment interactions.		
Environmental and Human Health	**11111 11**	**7**
– More microbial Metagenomes for biogeochemistry, pathogenicity, resistance. – Finding new surrogate species from environmental organisms that model human physiology and can be used in drug development and understanding the risk of chemicals for human health, particularly in relation to inter individual susceptibility. – Predicting emerging infectious diseases. – Environment and Human Health interactions for example biodiversity and effect on specific health aspects in the co-localized human population.		
Integrated Effort		
Integrate Data	**1111**	**4**
– Maximal integration of available and newly-collected data. – Integrate environmental sampling to species names/existing knowledge and genomes.		
To Study Key Environmental Questions	**111**	**3**
– Integrated Omics approaches to study specific environmental questions (collaborative).		
Free and Open Bioinformatics	**11**	**2**
– Free and open bioinformatics systems – Training, metadata, collaboration, support.		
Recording of Understudied Areas, for example Ocean, Developing World	**1**	**1**

Ideas	Sticky dots for the cluster	Total
– Establishing integrated environmental and Omic recording in under-developed areas (ocean floor, Third World, etc).		
Multi Omics Approaches	**11111 1**	**6**
– Integrate multi Omics approaches to understand cell/communities as a whole.		
Uses		
Uses for Humans	**111**	**3**
– Functional metagenomics – searching for useful genes for mankind.		
Bioenergy Replacing Hydrocarbons	**1111**	**4**
– 'Bioenergy to replace' hydrocarbon 'fossil' dependency. Energybiome →		
– Bioengineering or biomonitoring to promote sustainability (post-oil economy).		
Engineering the Environment	**11**	**2**
– Ability to engineer the environment through organisms independent deployment of biologically derived functional traits.		
Non-categorized		
– 'Omni-ome'. DNA, RNA, Protein, metabolites and all interactions for non-model organisms →new models. Anything can become a model organism.		

4 The Competitive Edge

4.1 What are the latest trends in Environmental Omics Research (Globally)

Ability to handle volumes of data

- Availability of high-throughput.
- Collection of better meta-data.
- Data integration
- Multi-Omic data integration papers <31>.
- Generating data ↑ as opposed to generating knowledge →.
- Analysis tools for data.
- Sustainability, open access, attribution of data.

Volume of data changing the science

- Hypothesis generation based on data intensive science.
- Lots of Omic scale papers that are badly analysed, worrying trend.
- Dropping cost leading to increased - or more widespread - use.
- Availability to contract services/technologies/technology specialists.
- Choice of service models.
- Descriptive studies, rather than experimental.

Understanding of environments

- Metagenomes from a variety of environments (gut, soil, etc).
- Ecosystem observatories employing Omic technologies (NEON, LTER and NSF).
- Complete genomes for marine species, not traditionally covered.
- Identification and characterization of species of ecological importance.

Environment and health interactions

- Combining environmental and human health research.
- Modelling of predictive toxicology.
- Environmental forensics.

New methods and research technologies

- Environmental Metabolomic facilities – indication of other Omics coming on the scene.
- Geotagging of samples from the environment using satellite technology.
- Community Transcriptomics.
  - Meta-transcriptomics, with associated change in technology from micro arrays to sequencing.

Historical & evolutionary adaptive applications

- Reconstruction of past environments.
- Ancient Omics, DNA, lipid.
- Genomics of biobanked material across multiple ecological domains.
- Identifying natural selection in DNA sequences.
- Adaptation at the molecular level.
- Genetic and molecular basis of quantitative traits.
- Epigenomic basis of phenotypic plasticity.
- Using Omics to understand complex environmental stressor interactions and organism function. Moving away from single perturbations affecting organism fitness.
- Understanding the genetic component leading to differential susceptibility of strains and species to environmental change.
- Use of genomics to understand the history of life, and the imprint of past environments.
- Use of genomics to understand evolutionary development (evo/devo).
- Use of laboratory microcosms to understand environment.

Moving from lab to environment

- Moving from laboratory to environment.

Omics developments

- Single all sequencing.
- Single all manipulation with microfluidics.
- Unculturable organisms.
- Nanosims, raman, allow to target single cells.
- Sequencing rather than hybridization bond techniques.
- 'Combination-Omics' from DNA to metabolites.
- Emerging use of environmental proteomics.
- Small molecule interactions.
- More studies in population genomes and phylogenomics.
- Epigenetics/genomics.
- Single cell Omics.
- Non-coding DNA, evolution, regulations of expression, etc. Splicing, post transcriptional modification.
- Cytogenetics, chromosome structure and function, recombination.
- Investigating simple systems and finding they are complex.

Standardisation

- Improved bioinformatics.
  - Genome Standards Consortium
- Omic standards bodies.

Links & gaps

- Interdisciplinary linkages, in personal.
- Across domains, skills.
- Development of interdisciplinary skills/ability.
- Emerging skills gap in the area of Omic data analysis and integration.

4.2 What is on the horizon in Environmental Omics (Globally)

Shift in capability

- Paradigm shift in terms of capability levels.

Better technologies for generating and using data

- Massive parallel/10kb sequencing.
- Third generation technologies.
- High resolution analytical methods.
- Improved data quality/database.
- Improved pipelines.
- Improved standards/standardization.
- Improved access to data/storage areas.
- The end of the micro array by high-throughput sequencing.
- Maximizing use of data.

  - Improved data mining.
- Increased use of advanced techniques in the laboratory.
- Experimental testing derived from all of Omic output/data.
- Exploratory data mining techniques.
- Mechanistically-based models for unifying multiomic data.

Complex system methods
- Development of complex system methodologies.
- 3D spatial Metabolomic mapping (c 60 sims).
- Application of systems biology to ecology.

Environmental Monitoring
- Environment quality monitoring.
  - Robustness?
  - Quality?
  - Routine.
  - Communicated to all levels.
  - Influencing policy decisions.
  - Increased breadth of monitoring.
- More environmental diagnostic tools.
- Biodiversity tools.
  - Monitoring.

Health and Environment
- Understanding of pathogens.
  - Marine.
  - Economically important organisms.
- Integration between environmental Human Health science.
- Environmental virology.

New species/life
- Synthetic biology.
- Manufacture of custom designs/Life.

Projects
- TERRAgenome project.
  - Soil.
- 1000 Genomes (Beijing genomes).
- ELIXIR and LIFEWATCH.
- 10k vertebrate project.
  - Plant eq? <35>
  - Invert eq? <35>
- USA Floral Genome Project.
- Compositae genome (Sunflower) project.
- Gordon and Betty May Foundation (AQUATIC VIRUS).
- Completion of global Metagenome project.
- GOS.
- 1000 Nematome Genomic Project.

Public use of Omics technology
- IPhone app for genomic analysis.

Management
- Increased levels of outsourcing?

Unsorted
- Joint sequencing of genome and epigenome.
- Epigenetics.
  - Population epigenetics
  - Developmental stages.
- Comparative analysis of full genomes.
- Transcriptomics of full environmental samples.
  - Capillary metabolomics.
- Meta-metabolomics.

- Meta-proteomics.
- Single molecule sequence.
- Engineering large Metabolomic pathways.
- Hand-held sequencing.
- Whole genome landscape genetics.
- Role of NON-coding RNA controlling gene expression.
- Genetic basis of development.
- INTRA-organism interactions.
- SOIL INTERACTIONS.
- Meso/macro phyllic genomics.
- Minimum viable organism.
- Barcoding database.
    - Animals.
    - Plants?
- Multiple stressors on organisms.
    - Individual.
    - Community.
- In silico fishing.
- CAT scans of natural ecosystems to a molecular level of resolution.
- Autonomous Omic monitoring solutions/systems.
- Characterization of novel environments.
- Determining signatures of alternative life forms deep past.
    - Prions?
- Detailed comparisons between post climate and communities.

Understanding differences between living and non-living processes.

- Population genomics <24> <56>?
- Personalized metagenomics.

4.3 What do you think the UK research community can uniquely offer – what is your USP?

Long term data sets

- Long-term data sets and monitoring to build on.
    - Eg Continuous plankton record.
    - Eg Closely monitored terrestrial vertebrate ecosystems.
- Non-expert access to experts and facilities.
- Long-term experimental field sites, for example Rothamsted soils.

Intellectual/research strengths

- Intellectual strength in ecology and evolution
    - Eg Experimental strengths in evolution ecology including host-parasite co-evolution. “Darwinian medicine”.
- Strong theoretical base - Challenges are conceptual rather than technological in many instances.
- Strong disciplinary base on which to build.
- Spatial temporal analysis expertise.
- Innovative (past?) in environmental Omics.

Leading in biomolecular sciences

- History of unifying ecology and molecular sciences.
- Lead in ancient biomolecular science <29>.

Unique collections and samples

- Collections, for example Kew, NMH, Western Channel Observatory, Antarctic (polar).
- Unique sample sets

Environmentally aware country

- Huge public cohort (stakeholder communities) with interests in the environment. - Lottery investment because of this
- Algorithm and software development.
- EU perspective – UK viewed as environmentally aware – potential public support for research. - Lottery investment because of the above

- Economic green drivers.

Strong industry and agricultural base and links

- Strong industrial base in molecular science.
- Highly efficient agriculture base.
  - Could be used more effectively.
- Technology innovation, for example spin-out companies.
  - Possibly not as effective as might be …
- Research community – industry links.

Uniqueness of UK geography, habitats & human influence

- Easy access to marine habitats.
  - Deep ocean, continental shelf.
- Unique environmental gradients underlying geology – terrestrial to marine.
- Highest density of habitat diversity per unit area. <28>
- Do we have any unique pathogens?
- Logistics and opportunities to exploit extreme environments.
- High human population density and associated environment or stresses.
- Global access to variety of habitats, ecosystems etc (Empire history).

Research Councils

- Research Council support for hypothesis generating research.
- RCUK history of direct investment in community building.
- RCUK funding mechanism does not inhibit multi-institutional projects.
- Diversity of research NERC supports.
- Lack of bureaucracy in RCUK funding of EU funding.

Funding system

- Well-funded science base to date …
- Democratic and formalized (peer reviewed) funding system.

Size and nature of the research community

- National capabilities (diversity).
- Size of the UK science community.
  - Not too big/not too small.
  - Facilitates formation of communities
- Balance between academic and government institute-based research.
- Experience in running shared facilities.
- Fundamentally cooperative ethos.
- Integrative science.
- Flexibility.
- Balanced and pragmatic approach to stakeholders.
- More national survey centres and associated data resources.
- Competitive delivery (papers/£). Including training and expertise.
- Well-trained good talent and education base.
- Engagement with data management community.

Research Approach

- Balance between strategic, fundamental and applied.
- Hypothesis-based research (few ‘fishing trips’).
- For most of the above the differences are quantitative NOT qualitative.

Across EU collaborators

- Cross EU collaborations, funding opportunities.

UK slipping

- Database development and delivery in environmental Omics less effective due to under-resource (UK generally lead).

4.4 How can we keep on the cutting edge?

Keep up to date

- Keep up-to-date with new technologies, for example Cloud Computing.
  - Post Light Technologies, for example Ion Torrent Oxford Nanopore.
  - Workflows on the “Cloud”, Galaxy.
- How do you keep up with technology evolution? ‘Rolling investment’ not one-off.

- Respond flexibly to new technology.

Developing and using new methods/technology

- More involved in basic technology development (rather than inheriting from other fields). ‘Science-led’.
- More thought into required techniques rather than using those available.
- Collectively assessing emerging technology.
  - Do they deliver?
  - Should we buy one? Etc.
- Linking technical development and quantitative/theoretical science.

Increase access to technology

- Provide access to large-scale infrastructure.
- Make access to cutting edge technology easier.
- Horizon scan better funded technology development, for example biomedical.
  - Risk applying within environmental research.
  - Don’t reinvent the wheel.

Keep research institutes and universities

- Keep flexibility of research institutes and universities.

Foster think tank culture within UK and wider

- Think-tank culture to generate new ideas (for example NCEAS, US National Synthesis Centres run sabbaticals, workshops for coalescence of ideas) (1).
  - Also the ‘Garden’ Conference model.

Work with and become international leaders

- Encourage international collaboration with leaders at cutting edge.
- How does the UK reach the level of International leadership?

Large institutes

- NEED large National Institutes for Omics.
  - Wet science, bioinformatics.

Support Academic sector

- Supporting/strengthening academic sector (currently being eroded).

International programmes

- Promote international programmes.

Better communication of research results

- Results need maximum exploitation, dissemination.
- Re-think the way Genomics data represented and reviewed in journals. Too much information/data to check.

Better ways of funding research

- Tax breaks for industry to best support research.
- Environmental research made VAT exempt.
- Be brave with disinvestment and strategic with reinvestment.
- Sandpits ‘£5M’ funding.
- Open up to international funding.
- Support long-term funding to encourage high risk/high reward science.
- Funding best scientists/best ideas (Marie Curie Research Centre model).
  - Longer funding for best scientists (10-year grants).
- Pay for its share of genome sequencing.
- Don’t cut national capability or logistics, includes:
  - Investment in facilities.
- Demonstration – stream funding under Framework 5 (EU).
- Joint resources between different funding Councils.
- Fund gap between science and application.
- Follow-up funding. Break 3-5 year cycle.
- Dragons’ Den-style funding for novel ideas.
- Provide access to seed corn funding (easy access).
  - Move wacky ideas that do not make it through peer review.
- Faster, simpler funding procedures.
- Fund basic research with no applied or short-term impact.
- NERC overlaps with other funding bodies (no gaps where projects can fall between).
- Generally increase funding.

- Keep funding coming.
- Keep as much money as possible in 'responsive' mode.
- Rewards for innovation.
- Made ideas funding scheme.

Standards & ethos
- Clear and transparent stance.
  - Data standards.
  - Quality of data.
  - Quality of storage of information.
  - (Becoming more and more a personal responsibility).

Be integrated and interdisciplinary
- More thought into integration of disciplines.
- Promote cross-disciplinary research.
  - Light risk research.
- Promote interdisciplinary research.
- Promote interdisciplinary permanent positions.
- Promote cross-over projects between human health and environment.

Focus on the right science
- Do the right science.
- Focus (eggs in fewer baskets, strength and depth rather than breadth).
- Focus on strengths.

Collaborate with industry developing the cutting edge
- Close collaboration with Industry developing the cutting edge.

Value blue skies research
- Innovation is key.
- Be proactive and foster the development of new ideas.
- Promote speciality research that is not inter-disciplinary. 'Blue Skies'.
- Change perception – move back towards 'risk' (riskier projects).

Influence policy makers
- Better communication with politicians.
  - Minister for Science (across the UK).
- Improve ability to lobby EU.
  - And receive funding from EU.

Invest in next generation scientists
- Fund training in Omics (Masters, PhD) – all aspects, sabbaticals, exchange visits.
- Introducing Genetics in schools, as early as possible.
- Teaching-focussed PhD projects.
- Be allowed to be tough with Undergraduate students.
- Teach Omics to Biology students – and Maths and Computing (and *vice versa*).
- Omics in schools, and in Undergraduate courses.
- Strengthen science teaching in schools.

Raise public awareness and interest
- Public dissemination to keep Public interested (1).
- Raising awareness of the Public.

Staff development
- Secondment.
- More sabbaticals.
- More fellowships, gap between PhD and permanent positions.
- Ensure appointment of new academic staff (due to cuts, may not happen).

4.5 What do we need to do to convince funders that Environmental Omics researchers can together deliver really worthwhile results?

Demonstrate impact
- Demonstrate impact.
  - Scientific, economic.
  - Look at wider benefits to society.
  - Demonstrate the wider value and impacts.

- Look for high-quality science with wider impact?
- Identify potential applications.
- Assess impact of Omics versus non-Omics papers.
- Compile a short list of the top (for example 6) massive impact projects and tell the world, for example brief PIs. Put this on a dedicated web-site.
- Demonstration projects to show off new technology.
- Analysis of previous impacts and synthesis Particularly in regard of EG and PG&P initiatives.
- Show economic impact of past research - Demonstrate a step-change
- Demonstrate Value for Money + general value.
- Stop worrying about the technology (lobbying for Omics) and focus on real questions.
- Robustly/demonstrably predict future responses to change.
- Demonstrate sustainability of research, for example databases don't disappear after 3 years.

Charismatic science

- Focus on clear and spectacular examples.
- 'Blue Skies' thinking.
- Should we do power-child science? Sequence charismatic things.
- What are Britain's poster species?
- Work on our museum specimens and in all different environments we can access the Antarctic and Arctic.
- Sequence a whole biosphere.

Communicate and excite interest

- Excite people.
- "Send the knowledge to where it is needed."
- More articles in Planet Earth, New Scientist, Scientific American.
- Doorstep science journalists.
- Define "Omics" clearly and consistently.
- Communicate to local politicians – Local Government.
- Institutional support for scientific communications.
- Publish.
- Publish collaboratively.
- Other communication than publication.
- Employ publicists and science communicators - Involving embedded science communicators
    - Training for scientists in communications
    - More time needed.
    - Embedded people who can communicate.
    - Put in knowledge exchange as part of grants.
- But analytical capacity – can the data be digested to give worthwhile results?

Ideas for communication

- Have community champions – in positions of power/influence.
- 'Sequence my garden' lottery.
    - Involve the Public – PR.
- Look to simple concepts – for example CBOL – easily sold.
- Let the Public into science stations or property.
- Maybe a UK 10k project – everyone can bid in for this.
- Scientists can use events like strategy launches to find out about public opinion. Make more of public outreach events.
- Can professional societies help? Is there one? No. Does there need to be one?
    - User Group. Look at "Team Scotland" approach.

Policy Relevant ?

- Policy – relevant.
- NERC says Government policy – relevance is less of an issue – fundamental science and/or NERC strategy.
- Emphasize knowledge-based economy.

Show Demand

- Show that demand is greater than supply. Based on 24 or 25 proposals which are not being funded. Look at proposals submitted
- Communicate the need for discovery – model work.
- Demonstrate the need for research.

Identify funders and help them understand

- Train the funders - Things like MP shadowing.
- Identify who the funder is.
- Convince funders of your priorities – that they are clear.
- Is there this need in the first place?
- Identify the issues they care about
- Recognize that funders will not fund your self-fulfilment.
- Funders care about human health and welfare.
- If funder has questions, where do they go?
    - Who is the expert?
    - Is there a database of who does what?

New partnerships and talent

- Industrial stakeholder/NGO partnerships.
- Developing a talent pool, for example for industry. Capacity building.

Integrated and cross disciplinary

- Coherent, integrated efforts across all work.
- Cross-discipline projects.

Smart objectives

- Short and long-term objectives, S.M.A.R.T. objectives.

Data sharing

- Clear data sharing policy.

5 Working Effectively Together to have a bigger impact

To make the most of the opportunities we need to work effectively together.

5.1 What are we already doing that is going in the right direction?

Capacity & Facilities

- NBAF – NERC Biomolecular Analysis Facility.
- Research and facilities.
- Bio-Linux and access to other software programs.
- Building capacity.
- mmmmmm
- Facilities.
  - NERC Centres.
- Open access databases.
- Good facilities in place.
  - Need to share knowledge between users.
  - Users meeting at central 'hubs'.
- Virtual collaboration – software package 'R'.
- No virtual collaboration on data analysis.
- We have created the NBAF.
  - Does it serve all the NERC community? Wider community?

Themed Programmes

- From 'birth to death', the full product lifecycle.
- Hub and Spoke models for Bioinformatics.
- Directed thematic programmes.
- Thematic programmes.

Research Communication

- Distributed bioinformatics support at a UK level (but not at a NERC level).
- Publishing results at a high level.
- Publishing quite prolifically across the UK.
- Networking.
- Symposiums.
- Knowledge Transfer

Funding & conditions of funding

- Co-funding mechanisms for recognized excellence (resources, facilities).
- Funding of environmental Omics in 'Blue Skies' mode.
- Small 'proof-of-concept' grants.
- Investment in responsive mode.
- Good at securing non-UK funding.
- NERC ring-fenced funding for environment Omics in a programme that meant people worked together.
- The second NERC programme (PG&P) 'forced' people to work together more.
- NERC support consortia.
- NERC funded Knowledge Transfer and workshops.
  - Working with Environment Agency.
- NERC co-funded a fellowship with EA.
- Directed funding initiatives.
  - Involving a meeting of the research community to define the direction.
  - There is evidence that EG and PG&P did its job. <10> Follow up evidence.
- Arabidopsis/drosophila centres – BBSRC funded – being used by NERC.
  - Do we know how much cross-Council activity is happening?
- Many people with NERC grants have, for example BBSRC grants.

Student involvement

- Student support work.
- Training students in science generally.

- Undergraduates.
- Post Graduates.
- Fellowships.

Collaboration

- Being here today – community-wide workshops mobilizing the community.
- This meeting demonstrates a range of interests with a shared use of Omics technology.
- Collaborative approach.
- Good at leaving LEADING international projects?
  - Punching above our weight?
- Using collaborative facilities
- NERC expanding collaborative facilities.
- Research Councils talking together more than previously.
- Actively talking across disciplines.
- Collaborative projects.
- NERC meetings expose participants to different fields.
- End users talking with researchers.
- Collaborative projects.
- Training of new skills.
- Going outside comfort zone.
- Willingness to interact.
- Transparent community engagement workshops.

5.2 What do we need to do more of?

Training & Support

- Advanced training courses, continuing professional development.
- Training – targeted studentships, courses, capacity building.
- Students working across laboratories, exchange visits.
- Training fellowships.
- Advice, training, support needs to emerge from centres like NBAA, not just doing the job.
- More exchange? Workshops? Training – support.
- How about personal fellowships/studentships?
- Increase local knowledge so people can do all the steps.

Facilities & technology access

- Transparent access to high performance computing facilities, Cloud computer resources, no down-time.
- More cross-Council projects, including resource provision and facilities.
- Facilities need to be more accessible.
  - Level of awareness?
  - Speed of access.
- Fast track access needed.
- Having technology.
  - People meeting over the technology.
  - Something that will do the job.
- Cross-Council use of facilities – we need to be clearer and promote access.
- We need to avoid duplication.
- Recognize competition in facilities.
- Should we look at UK-wide or specialized (for example just NERC) facility?
  - Arguments on both sides.
  - Duplication, efficiencies.
  - Ability of facility to meet needs of users.
- Wellcome facilities as well.

Improve Funding opportunities and continuity

- More follow-on funding opportunities.
- Funding consortia within institutions – across disciplines.
- Funding for projects in between the two post doc level and the consortia level – no equivalent to single institution BBSRC LoLa.
- Want a funding stream for international collaboration.

- Better continuity for research.
  - Longer contracts.
- NERC to communicate the opportunities better – there are schemes but clearly not well known.
  - Targeted communication
- Funding for collaborative networking – encourage research networks.
- Specific funding opportunities.
- Co-sponsorship between Research Councils.
  - Proactive communication.
- Okay to have technology but need funds to be able to use it/collaborate.
- Joint programmes between Research Councils, for example LWEC initiative.

Improve communication

- Transparent communication of successes.
- We are not very good at communicating our science.
  - Public.
  - Politico?
  - Press/media.
- Mechanism for more easily finding out what is already happening – Facebook? Social networking?
- More effective PR.
  - Fewer, but more appropriate, people.
  - Depends on type of research
  - Identify project strengths and needs.
- Embedded in virtual network.
  - WiKi.

Remove barriers

- Removing boundaries to aid introduction into field.
  - Points of contact.
- Better information of what is available.
  - Databases.
  - Tools.

Find a trust and high profile people to promote environmental research

- Look to example of Wellcome Trust. Can a similar body promote Environmental Research?
- The Wellcome Trust can strengthen departments.
- Can we get high-profile people involved? Bill Gates was mentioned. Entrepreneurial benefactors.
- We need to know the right people – should be open to all – less cliques.

Engage with end-users

- Knowledge exchange working directly with vendors to address the needs of the environmental community.
- More engagement with industry and other stakeholders, with more active involvement from NERC to foster this.
- Need more mechanisms to do collaborative research with end users, for example CEPAS.
- More incentives for collaborative research – it's hard to persuade end users to provide funds.
- Successful Knowledge Transfer between university and agency <30>.

Collaborate

- Better interaction between fields.
- Abolish the REF so easier to work collaboratively.
  - Get published.
  - Other outputs.
- Joint activities between scientific societies – meetings, workshops – dedicated Omics sessions.
  - Though some people are against this because ends of focussing on technology not the basic science question
- Finding opportunities for crossing barriers.
- Having a problem that is of interest to many people.

New themes

- Another thematic programme to take the NERC Omic strategy forward.

Cutting edge to routine

- Bringing cutting edge research into routine use.
  - Robustness.

  - Ease.
  - Quality.
  - Make cutting edge mundane.

New technologies

- Getting a foot into new technologies.
- Tailoring technology to environmental needs <8>.
- Mechanisms for developing novel technologies, resources.

All of the above

- All of the above!

5.3 If Omics is to be increasingly used in environmental science, what training and skills development do we need?

Bioinformatics training and career path

- Sessions at conferences 'Bioinformatics for Dummies'.
- Help with bioinformatics.
  - Bioinformatics for Dummies.
  - What to do with the data.
- Bioinformaticians need to 'spread their love' <21>.
- Bioinformatics modules within courses and *vice versa*.
- Fast track for new/novel applicants? (People moving INTO bioinformatics from outside biology).
- Informatics for all.
  - This is done in Melbourne.
- Should be able to develop a career as support bioinformaticians.
  - Did happen at Sanger Centre.

Discipline hoping

- More discipline 'hopping' training for students/early career for environmental Omics.

Awareness raising amongst supervisors

- Awareness training for supervisors and principal investigators, for example 2-hour session on all the Omics and multi-Omics technique.
- Suggest a new role for experimental support officers.
  - Hard to fund.
- People who can do laboratory work and informatics.

Start in Schools

- Start in schools.
- A coherent curriculum post 16, for example all science students doing some maths.
- Increased access and variety of learning approaches.

Undergrads

- Dedicated training in Omics for science Undergraduates.
- We may be failing at Undergraduate level. Many notable biologists never did Undergraduate biology. We target training to PhD students primarily.

Masters

- Masters-level courses aimed at conversion, for example biologist learning computing. Maths/biology.
- Masters in Environmental Omics.
- Dedicated Masters' programmes.

Master Classes/summer schools/workshops

- Well-funded international NERC summer school.
- Fund master classes in Omics– one week intensive course: get in science star speakers, one-third lectures, rest hands-on.
- Also on different types of Omics or on a particular environmental question.
- Students.
  - PI's
  - Summer schools for PIs.
- Sabbatical scheme – chance for PIs to take time out. Especially for data analysis.
- Workshops for new techniques.

Sabbaticals and secondments

- Short-term secondments.

- International sabbaticals.
- Funding secondments.

Charismatic communicators and engaging events

- TV personality to champion Omics – or Omics expert to become a TV personality. Need boy-band looks! - For example Brian Cox and Peter Kille.
- A multi Omics Roadshow.
- YouTube.
- Better use of webinars.

Experiment & project design

- Experimental design.
- Help with experimental design.
  - Sometimes samples are just wrong.
  - Doesn't always have to be hypothesis driven.
  - Data – and hypothesis-driven analysis.

Grant-writing skills

- (1) Media placements.
- Training in writing impact statements (1).
- Encourage the identification of skills gaps in grant writing.

Annual Conference

- Have an NBAF annual conference.

Consortia and centres of excellence

- Should we have more emphasis on consortia?
- Formation of multi-disciplinary teams.
- Alternative to consortia is centres of excellence.
- Does the researcher need to understand the nuances of every new approach? Maybe not, but risk of distancing.

Other comments

- Fast track pilot projects.
- Programming in 'R'.
- Creating polymaths, digomaths.

5.4 Who are the other Environmental Omics funders

Easier to ask "Who aren't"!

Europe

- EU.
- EC.
    - ERC.
    - ESF.
    - FP7.
    - RTD.
- CEFIC – European Chemical Industry Council.
- Overseas.
- European RC.

UK Research Councils/RDA's

- AHRC (Arts and Humanities Research Council).
- All Research Councils.
- BBSRC Biofuels.
- Bioinformatics.
- EPSRC (2).
  - (2) Maths
- MRC.
- RCUK.
- Regional Development Agencies.

US foundations & agencies

- ACC – American Chemical Council.

- NSF.
- Overseas, for example US EPA.
- USDA.
- USEPA.
- Venter Inc.

UK government depts/agencies

- CEFAS (?)
- DEFRA – they should be brought in possibly.
- DEFRA via FERA. (Food and Environment Research Association)
- Department of Defence.
- DOE.
- EA – Environment Agency.
- Health Protection Agency.Environmental Health.
- SEPA (Scottish Environmental Protection Agency).
- SERA.
- TSB.
- Scottish Government funding via SCRI.

Charitable trusts & national bodies

- Cancer charities.
- Charities (other than Wellcome Trust). For example Cancer Research. - Marie Curie.
- English Heritage.
- Foundations – Moore, Sloane, Total, Gates.
- Gates Foundation.
- Leverhulme Trust.
- Museums, for example NHM.
- Royal Society of Chemistry.
- Wellcome Trust.

Industry

- AstraZeneca.
- Chemical companies.
- Industry, for example support courses.
  - Pharmacology.
  - Plant-breeding.
- Industry, Syngenta, oil companies.

Water companies

- SGPA.
- Water companies.

Universities

- Universities.

Global

- World Bank – Reef Project <32>.

Australia

- CSIRO – Australia.

Czech Republic

- NCBR – already co-funding.

5.5 How can we work effectively with other UK Environmental Omics funders?

Knowledge transfer

- Getting together for workshops where exchange information.
- Knowledge Transfer mechanisms.
- Knowledge Transfer programmes.
- Better communication.
- Knowledge Transfer network.
- Partnerships.

Work with each other

- BBSRC has plant microbial sciences community.
- Omics interaction with BBSRC and MRC.

  - Borrowing knowledge.
  - Best Practice.
  - Give money to organize workshops.
  - Inviting experts from other fields.
- Share technologies – BBSRC.
- Hubs for ELIXIR, NEBC.
- There are already umbrella organizations and fora. Can we make more use of them?

Use infrastructure differently

- Complimentarity amongst facilities.
- Better sharing of infrastructure.
  - Each has their own.
  - Separate dialogues.
- Using infrastructure as hub for directed funding.

Joint funding and working

- Inter-disciplinary research teams.
- Joint calls.
- Joint funding capacity.
- Co-funding agreements.
- Bilateral funding – ERA-NET.
- Identify common goals and common priorities.
- Proactive planning for Framework 8.
- Identify cross-cutting grand challenges.
- We tend to ask lots of small, specific questions.
- Joint initiatives possible.

Applications easier

- Streamlining applications.
- Clearing houses for project applications.

Funding

- Get a clear idea of what funders will or will not fund.
- Ring-fenced money from cross-Council developed thematic programmes.
- (ERFF – talking-shop – now overtaken by LWEC – not a good solution for funding).
- DEFRA and EA funding should increase as tools become more mainstream.
- A lot of what we are offering are better toolkits, diagnostics, predictions.
- Met Office? No.

Industries and research

- A formal advisory body so relevant companies can say to NERC we want to do research on this; the TSB (Technology Strategy Board) have this role.
- Speed dating event with companies.
- Industry collaboration can be specialist.
- Straw poll – nobody gets money from industry.
  - The above is not 100% true.
- Spinouts – can result from research and bring in cash.
- Initiatives already exist in 'science' to have funding.
  - 50% academia.
  - 50% industry.

Top up grants

- Top-up grants if technology changes.

Research Council funding

- Addressing bottlenecks by balancing capacity across Councils.
- Encourage NERC to have cross Research Council funding.
- NERC should employ more people from multi-Omics platforms.
  - To bring ideas.

Health agenda

- We get maybe pence from the Medical Research Council but health and environment are related.

Training

- Joint funding of training courses.
- Training people in the data they are looking at and how to analyse.
  - Mathematicians/modellers/non-genomics people to study it.

  - Stimulate people (Computational People) to work on meta-analysis.
- Technology training.
  - How to use it.
  - Future technology – all technology.
  - What is possible?

Link with research fields

- Link to ecological theory and evolutionary biology.
- Apply Omics techniques to phylogeny.
- And to evolution and functional analysis.

Philanthropists

- Approaching philanthropist.

Technology development fund responds to community

- Technology development fund that facilities can call on if there is a demand from the community.

5.6 How do we communicate more effectively to those for whom Omics is a new subject

A reason to communicate

- No one understands Omics outside Omics – this is not very sustainable.

Make Omics exciting and attention grabbing

- OMICS BUS with sequencing on board, with bulletin board on the front with real-time updates.
- Omics festival – engaging young and old.
- Omics hot-air balloon.
- Science festivals.
- Take ideas out to masses.
- All 'consumers'.
- 'Omics' the movie.

Media

- Have a job to target mass-media, New Horizon, get it into New Scientist.
- Media coverage.
  - Nature paper *versus* television.
  - Related.
  - Press office outreach.
  - Sell science ASAP.
- Use the popular media and Planet Earth.

Talks

- Public lectures.
- Training – 2-hour intensive audience with charismatic person.
- Bring in Omics 'stars' from overseas.
- High profile conference with the charismatic characters.
- Sessions at conferences.
- Guest speakers.

Publications

- Simplified/accurate publications.
- Brochures, handouts, pamphlets.
- Two-sider summaries.

Communication training

- Media communication training course for Omics expert.
- 'Writeshop concept' (ask Diana Pound if want to know more).

Technical seminar

- Have a technical seminar on data types.
  - Future data.
  - Need to put it in context.
  - Even legal people.

Websites

- Website – need to share at novice level, and can click on levels going deeper (3).
- Websites.
- Six show-case highlights on website for others to see.

- Make relevant.
- Punchy messages.
- Emphasis on UK.
- Aspirational – show what is happening elsewhere.
- Inspirational.
- Basic Wiki, for example Wikipedia.

Stakeholder workshops

- Multi stakeholder workshops.
  - Around themes.
  - What is possible here and now?
  - Particular subject, for example toxicology.

Champions

- Champions of Science.
  - Can relay complex science to public.
  - Need good case examples.

Messages to communicate

- 'Factoids'
- Communicating the potential.
- What Omics can do for you?
- Integration where it is part of larger investigation.
- What is the problem they need to solve?
  - Is there a specific question?
- Themes driving collaboration.

Make it assessable

- Target communication to audience.
- DEFRA Omics easy reader.
- Get rid of jargon.
- Re-write the information from this work in a 'plain language' accessible way.
- Slowly and clearly.
- First try to do it ourselves.
- Have an interesting science question.
- Need to get a base understanding of Omics.
- But this is not a discipline in itself.
- That this is nothing so new, just a better way of gaining and integrating knowledge.
  - People should not be intimidated.
- The term means so many things to so many people.
- "Could someone define it for me?"
- The people you can reach depends on the definition taken.

School education

- Omics in schools.
- Resources of schools, policy–makers all in one place.
- Contact leading educational websites.
- Putting science examples into school textbooks.
  - Earlier learning/teaching.
- Increase outreach as an academic.
  - Pre-university.

To potential funders

- Funders.
  Interaction with team leaders.
  Targeted reviews in publications.
  Successful examples.
- Successful case studies.
- See potential.

5.7 Out of everything you have heard and discussed, what are the two priority actions that you most think will help to support delivery of Environmental Omics Research?

Real world outcomes

- Real-world outcomes.
- Funding of deep genomics – of significant scale to make the difference, for example allow for delivery on potential.

Champions

- Experts:
  - Funding of professional 'Genomic Tsars'.
- Fund fellowship-level champions in the different technology areas who will collaborate with NERC researchers to get integrated Omics taken up.

Build on solid knowledge base

- Build the discipline of Environmental Omics on established theories of ecology, evolutionary biology, etc.

Community agreed themes and goals

- Community focussed and agreed common goals in a directed programme (NERC or RCUK).
- Mechanisms for more effective cross-Research Council cooperation in identifying key "grand challenges" in environmental Omics.
- Few focal themes/projects that allow for 'deep delivery'.

Cross council working

- Cross-Council developed thematic programmes.
- Cross-council coordinated resource provision and bioinformatics.

Community led demonstration projects

- Community-led demonstration projects.

Systems thinking and workshops

- NERC funding inter-disciplinary international systems science workshops.
- Systems thinking, systems approach.

New virtual or real centres to do exiting work

- Promote the establishment of a 'virtual' Environment Sciences Institute (to mirror what Wellcome Trust has done for medical sciences).
- Support for science, training Knowledge Exchange and facilities (including data management).
- A centre that facilitates development of items to a fundable level!
- A major environmental Omics informatics analysis hub.
- Well-funded centre/facility providing infrastructure and support.
- Establish a national facility in Omics (expand N-BAF). Advice/expertise in wet science and bio/Ometics/technology and supply. (TRAINING, Data Management, QA in computational science/biology.)
- Centralized facilities engaging in support and research and development of new technologies.

Accessibility to cutting edge technology, data and facilitates

- Access to cutting edge technology.
- Better access to research facilities available (more information and more funding to improve access to facilities).
- Accessibility:
  - Increase access/speed to data analysis platforms.
  - Increased accessibility of central facilities.
- Greater effort in creating complex bioinformatics solutions that are freely available and relatively simple to use.

Capacity Building

- Capacity Building:
  - Bioinformatics capacity building within the existing academic community.
- FREE SEQUENCING. More capacity than demand.

Informatics support

- Expand the growth of NERC facility (NBAF) to include better informatics support and additional Omic technologies.

Make NBAF even better

- Build on NBAF to provide:

- New technology.
  - Real biddable resource.
  - Training.
  - Networking/conferences.

Uk fund for genome sequencing and support

- A UK fund for genome sequencing (and support) – we have to pay our share and not follow the US and China. 10,000 genomes (across, within species, within communities. UK Biome/UK 10k Biome.
- Development of Bio information support.
- Mechanisms for more effective multi-agency collaboration in providing access to cutting-edge technologies in Omics.

Training

- A well-funded Omics summer school delivering training across PhD to PI on bioinformatics, statistics, modelling …
- Better training in new techniques and Data Analysis, for example bioinformatic training.
- Fund dedicated training programmes – short courses, studentships, showcases, discipline-hopping.
- Promotion and funding of cross-disciplinary groups. Combined with improved training opportunities.
- Training.
  - Training at all levels – Undergraduates to PIs.
  - Training at all levels (students, Postgraduates, PIs).
  - Increase numbers of bioscience-trained bioinformaticians.
  - Funding of innovative multidisciplinary approaches/studies.
- Studentship/fellowship/sabbatical level training opportunities.

Funds or vouchers for new users

- Funds or vouchers for new users to access the necessary technology to 'enter' the Omics field for their environmental research.

Interdisciplinary Fellowships

- Interdisciplinary Fellowships.
  - Math to Env.
  - Env to Math.

Communicating really effectively to new audience

- Communicate to non-Omics scientists the benefits and limitations of Omics.
- Increased Public/general awareness of the potential afforded by Omics research for knowledge discovery.
- Communication to funders:
  - Communication of science benefits to science funders/politicians.
- Document super-success stories in environmental Omics, using a highly visible platform (for example web) in transparent language, and disseminate to key funders.
- Improve communication of benefits of work and need for further work to stakeholders.
- Making understanding of Omics accessible for all.
- Define the discipline clearly and explain to research community and wider public what Environmental Omics can deliver.

Funding

- Money:
  - 50 times more money to NBAF.
  - Investment in high quality responsive grants.
- Dedicated funding programmes across disciplines.
- Better communication of – and support for – cross-funder opportunities.
- Increased funding for collaborative projects.
- Access potential for cross-funder coordination and integration of resources and training.

A trust raise the profile

- A 'Wellcome Trust' for environmental research to raise the profile of environmental science within HEIs.

Don't isolate Omics

- Do not isolate Omics – associate it with physiology/taxonomy …

6 Parked Items

6.1 Parking Place

- Peer reviewers not believing what is possible.
- Funding bodies focussing on well-studied systems/ideas/techniques.

6.2 What does this mean?

- Epigenome – is the way the genome is modified without the genetic base information being changed.
- Surrogate species: species that better model humans for toxicity testing, particularly for drugs. For example, are there lower order species that would replace higher order species and give the same output, or even improve output?
- UK 10k

New words invented today?! Eg.

- 'DNA-arium';
- 'Omni-omics'
- Systomics.

7 Actions following the workshop

7.1 Short term

WHO	WHAT	WHEN
CEH	Type up	Completed in two weeks directly after NEOMICS Town meeting (April 20-21)
dialogue matters	Emergent processing (as far as possible given knowledge of the subject)	Sent to CEH on June 23rd
CEH	Finish sorting any unplaced or misplaced comments	Sent to Chair June 30th.
CEH	Send out to all	Post EWG meeting July 5th

7.2 What happens next?

This document will be used to inform the thinking of the NEOMICS Expert Working Group (July 5th meeting) and the NEOMICS Team. The results of this meeting will then feed into a synthetic report to NERC recommending a series of models that could be followed to fund ‘omic science. The NEOMICS consultation will end Sept 10 when this 10 page report is delivered to NERC.

Annex 1 List of Attendees

	Name	Role	Organisation
1.	J R Snape	Neomics Team	Astrazeneca
2.	Mike Allen	Marine Angle	PML
3.	A Gardner	-	NERC
4.	Ron Corstanje	-	Cranfield University
5.	Simon Hiscock	EWG	University of Bristol
6.	Steve Paterson	EWG	University of Liverpool
7.	Tim Ebbels	-	Imperial College
8.	Jim Prosser	EWG	Aberdeen University
9.	Tom Meagher	EWG Chair	University of St Andrews
10.	Bill Eason	NERC	NERC
11.	Danielle Ashton	Research Scientist	Environment Agency
12.	Dawn Field	Research Scientist	CEH
13.	Felix Forest	Research Scientist	RBG Kew
14.	Andy Weightman	Research Scientist	Cardiff
15.	Alfried Vogler	Research Scientist	Imperial College
16.	Joakim Larsson	Research Scientist	University of Gothenburg
17.	Tim Gant	Research Scientist	Medical Research Council
18.	Roger Butlin	Research Scientist	University of Sheffield
19.	J H Bothwell	Marine Biology	Queen's Belfast
20.	Tim Williams	Research Scientist	University of Birmingham
21.	Mike Bruford	Scientist	Cardiff University
22.	Sarah Collinge	Funder	NERC
23.	Francesco Falciani	Scientist	Birmingham University
24.	Dave Lunt	NBAF	Hull University
25.	Melody Clark	NBAF	British Antarctic Survey
26.	Frederick Verret	Scientist	NBA
27.	Mark Blaxter	NBAF	VOE
28.	Mark Bailey	Scientist	CEH
29.	J Thomas-Oates	Lecturer/Research	University of York
30.	Clemens Engelke	Senior Scientist	SEPA
31.	Mark Viant	Neomics Team/NBAF	University of Birmingham
32.	Charles Tyler	Neomics Team	University of Exeter
33.	Jane Rogers	-	TGAC
34.	Peter Kille	Neomics Team	Cardiff University
35.	Terry Burke	NBAF	University of Sheffield

Annex 2 Agenda

Environmental Omics… small molecules - big impact

Workshop of leading experts - 20 May 2010

The purpose of this workshop is to help shape the agenda of major new research. The workshop is to explore ideas for research into innovative Omics solutions that can help transform the way we manage and use the natural environment

9.00 **Getting Started** – Registration, starting activities.

It is 2030 and development and use of Omics knowledge has made an amazing difference. You and others are chatting and start listing the things that you can now do, that have make the biggest difference to how we understand and use the environment. For you the top two things are……..

Add your thoughts to those of others

9:20 **Welcome and briefing – why are we here today** Prof Tom Mehgher
Facilitators Introduction Diana Pound

9:45 **1. Exploring the context -** visit each of the topics below and have your say

What can Environmental Omics solutions do for:

- Quality of life?
- Quality of environment?
- Sustainable living?

Opportunities, challenges and trends for Environmental Omics research
Thinking about what may need strategic investment…

- What challenges are there for doing Environmental Omics research? (eg technological, bioinformatics or data management)
- What opportunities are there for doing Environmental Omics research? (eg technological, bioinformatics or data management)
- What do we need, to do good Environmental Omics research? (eg for technological infrastructure, bioinformatics or data management)

10:40 **Tea and Coffee**

11:00 **2. Developing ideas** – sit in groups and explore ideas

Thinking about innovative and high impact Environmental Omics research

- What are the big picture research questions the community would like to address?
- What challenges are there that Omics could help solve?
- How can Omics change the way we manage the environment?
- What are the most cutting-edge, innovative, synergistic ideas you can come up with to advance environmental understanding?

Out of everything, you have heard and discussed over the last two days what are the two research ideas that you would most like to see research focus on?

Fast Feedback

12.30 **Lunch**

12.30	**Lunch**

1:15 **3. The Competitive Edge** - rotate around the questions

The competitive cutting edge

- What are the latest trends in Environmental Omics research (globally)?
- What is on the horizon in Environmental Omics (globally)?
- What do you think the UK research community can uniquely offer – what is your USP?
- How can we keep on the cutting edge?
- What do we need to do to convince funders that Environmental Omics researchers can together deliver really worthwhile results?
-

2:10	**Tea and coffee**

2:30 **4. Working Effectively** – sit in groups and explore ideas

Working Effectively Together to have a bigger impact

To make the most of the opportunities we need to work effectively together

- What are we already doing that is going in the right direction?
- What do we need to do more of?
- If Omics is to be increasingly used in environmental science, what training and skills development do we need?
- Who are the other Environmental Omics funders?
- How can we work effectively with other UK Environmental Omics funders?

Out of everything you have heard and discussed, what are the two priority actions that you most think will help to support delivery of Environmental Omics research?

Fast Feedback

Last things

What happens next

No later than 4.15	**Finish**