Climate change research at Macaulay Institute

Context

Climate change is widely recognised as the most serious environmental threat facing our planet today, and is likely, therefore, to become central to policy-making and land-use decision-making within the next decade or two, and remain so for many years thereafter. The Scottish Executive has recently published its Climate Change Strategy (Scottish Executive, 2006a), in which one of the stated aims is to decouple the link between economic activity and carbon emissions. Subsequent policy documents for the forestry and agriculture sectors have also been published, in which addressing climate change issues is seen as a major challenge (Scottish Executive, 2006b; Scottish Executive, 2006c). Consequences of these for Scotland’s environment, land use, and rural communities need to be better understood, as do the management systems needed to encourage sustainable landscapes in the face of this change.

The agriculture, forestry and the land use sector acts both as a source of GHG emissions as well as a carbon store, contributing about 20% of total GHG emissions, but removing about 16%. Soils represent a significant C pool which may be susceptible to future global warming and changes in precipitation patterns, as well as changes in land use. The main gases emitted by the agriculture sector are nitrous oxide (N_2O) and methane (CH_4), with lesser amounts of CO_2 from land use change and energy use, with most of the CH_4 emissions due to enteric fermentation from livestock. Forestry makes a net contribution to reducing atmospheric CO_2 by carbon uptake in growing biomass, and through forest vegetation and soils. Various options for reducing the emissions of greenhouse gases from these sectors have been proposed, but there is considerable uncertainty as to their effectiveness or to the likelihood of their adoption, requiring further research.

Climate change will also affect most ecological habitats and species across Scotland. Several predictions have been made of the direction, degree and likelihood of effect, but these are based on rather simplistic relationships between species distributions and climate, and there is a need to obtain baseline data that take account of indirect effects exerted through relationships between species and through changing human impacts on the environment as a result of climate change. This information can then be used to identify where species compositions might be altered with southerly species arriving and/or northerly species retreating. Research is also needed to understand to what extent climate change impacts might be mitigated by management within species’ existing ranges.

The predicted shifts in temperature and precipitation will also have direct impacts on hydrological and biogeochemical cycles, which may lead to changes in river flow regimes or groundwater recharge, and increased frequency of extreme events such as flooding and droughts. Changes in the hydrological regime could also lead to indirect changes in water chemistry, as a result of erosion risk, leaching potential, and biological and chemical processes which are regulated by water availability. Temperature changes may affect physical processes such as freezing, thawing and evapotranspiration, as well as biological and chemical processes, all of which will influence freshwater ecology. These consequences require to be assessed together with identification of appropriate adaptation and mitigation measures, through planning and policy frameworks, for example, implementation of water resources legislation such as the EU Water Framework Directive.

It is particularly important, however, that in developing policy to support adaptation and mitigation efforts, the cost, benefits and trade-offs required are recognised to ensure that particular individuals and communities are not disproportionately burdened. The strategy documents emphasise the need for rigorous, integrated analysis that includes social and institutional factors rather than a piecemeal approach dominated by economic or biophysical science. This is a significant challenge for researchers, and requires both the breaking down of barriers to interdisciplinary research, and the active inclusion of stakeholders and policymakers.

Current climate change research

Previous and current work at Macaulay has focused largely on impacts of climate change on the ecology, soils, hydrology and land use of Scotland. For example, there is significant effort studying the likely impacts of climate change on changes in species distribution at multiple spatial scales, a key aspect of which is identifying uncertainties associated with such change, rather than simply making predictions of species re-distribution in response to climate change.

Work is also ongoing to assess the stock of C in soils and peats across Scotland so as to characterize this potentially vulnerable C pool. In collaboration with the University of Aberdeen, the ECOSSE model of C turnover, has been specifically developed to describe processes in the organic soils prevalent in Scotland. Other detailed modelling studies include an investigation of climate change impacts on dissolved organic matter in soils and rivers, and, in collaboration with SAC, on N_2O emissions from agricultural soils. Together with SCRI, we also analysing the potential impacts of altered precipitation patterns on both drought and water-logging, and, under more severe conditions, the implications for increased risk of soil erosion. More detailed process-based field research is characterizing the C flux within arable, grassland, woodland, moorland and peatland ecosystems.

Long term data collected from the Environmental Change Network (ECN) provides invaluable information for detecting changes in water quality such as that brought about by climate change, and will assist in the provision of an enhanced evidence base for its impacts. The potential impact of climate change on riparian ecosystems is currently being examined through an assessment of the relationships between vegetation, climate and the thermal regimes of streams. Many surface waters are currently recovering from nutrient enrichment from atmospheric deposition (S, N). The potential implication of climate change on the recovery of these systems is being examined using a space-for-time substitution method.

Other work is focused on assessing impacts of climate change on farming systems management units, using the farm scale decision support system (LADSS) developed at Macaulay. This work has included the development of an approach using Hadley Centre Regional Climate Model daily data (linked to the UKCIP02 scenarios) for site specific impact assessments, and which is evaluating the effect of uncertainty in the climate data on the decision-making processes of farmers. We are also developing and using the spatially-explicit People and Landscapes Model (PALM) which links human decision-making to soil carbon, nitrogen and water dynamics, in an attempt to understand the complex feedbacks between human and biophysical processes.

Planned climate change research

We plan to continue the work described above to develop in-depth understanding of the impacts of climate change in the core science areas of ecology, soils, catchment management, socio-economics, and land-use systems. For example, potential impacts of climate change on biodiversity and species distributions within Scotland will be investigated on a spatially-explicit basis, identifying those areas most likely to experience the greatest change in biodiversity. Since policy-makers require not only a measure of expected changes likely to occur, but also the uncertainty associated with such changes, measuring uncertainty will be an integral component of this research.

Similarly, the ECOSSE model will be used within a GIS framework to assess the impact of both land use and climate change on C cycling at the 1 km^2 scale across the country. The utility of implementing ORCHESTRA, an object-oriented modeling environment developed at MI, will be investigated for describing the more detailed process level work. The resampling over the next three years of the National Soils Inventory points, a grid-based set of sampling points across Scotland that were initially sampled over twenty years ago, will provide information on soil C and other properties where any changes may indicate climate change responses.

The process based catchment models of hydrology and diffuse pollution which incorporate a number of climatic variables will be further developed to enable improved understanding of transport processes at catchment scales. Future application of these models, using climate change scenarios, will enable the consequences of climate change on runoff processes and the generation of diffuse pollution to be evaluated and further to be linked with ecological responses. This will enable the identification of aspirational and achievable targets for recovery of freshwaters, given the hysteresis of their responses to pollutant pressure, nutrient enrichment and removal. In addition, factors such as frequency of flooding and drought conditions will be assessed. Specific research will be undertaken on dissolved organic matter to interpret the results of process studies on controlling processes and transport mechanisms in relation to climate change and hence to evaluate the potential impact on catchment receiving waters.

Increasingly, however, effort will be given to integrate knowledge from these areas to take a holistic view of how they integrate at the farm, community, landscape, national, and international levels. This knowledge will also be used, in collaboration with our key stakeholders, to explore the range of response strategies, including the mix of adaptive and mitigation measures. An important part of this research context is to be aware of, and consistent with, diverse social and institutional settings. With its unique advantage of natural and social scientists all working under the same roof, Macaulay Institute is well-placed to push the boundaries forward on this interdisciplinary approach. This will provide greater understanding and evidence of the human and environmental dimensions of climate change impacts contributing to rural sustainability.

For example, work is planned to investigate the nature of the barriers to the adoption of Best Management Practices for GHG emissions management at the farm level, using farm-scale case studies and multi-perspective deliberation. Other work will consider climate change as one of the drivers in the context of assessing trends in, and visions for, sustainable farming systems across Scotland, using national-scale economic and bio-economic modelling approaches. Responding to climate change will continue to be a key theme brought up by stakeholders in questionnaires and interviews in relation to catchment management, and will need to be better considered within the socio-economic evaluation of catchment management options. The adaptation of water resources management to climate change is also proposed to be considered using a Driver-Pressure-State-Impact-Response (DPSIR) framework for the characterisation process, as well as in the integrated modelling and appraisal of Programmes of Measures (POMs) in proposed methods for implementation.

However, we intend to focus increasingly on the whole rural sector, including rural industry and the wider rural population, rather than just the agricultural component, and to examine its capacity to adapt to climate change, including its contribution to GHG mitigation. One theme we plan to develop is the identification of practical and strategic options for rural communities to move towards low carbon economies by reducing GHG emissions, increasing carbon storage, and switching to alternative energy systems. To do this, we plan to integrate knowledge from the social sciences, economics, and ecological sciences to evaluate the impact of various policy options on all aspects of rural systems, and investigate the tradeoffs between individual interests of making a livelihood and the broader societal goals of mitigating and adapting to climate change.

A novel feature of this approach for enhanced scientific understanding will be the opportunity to address issues in the real world by the active cooperation of Aberdeenshire County Council and Cairngorms National Park Authority in using their respective areas as model socio-ecological systems. Such partnerships provide the opportunity to couple information on status and trends of the regions in both the biophysical characteristics (i.e. soils, land cover and land use data held by the Macaulay Institute) with social and economic data contributed by our partner organisations. Our aim is to develop a grounded and broad-based understanding of the realistic options for both adapting to, and mitigating of, climate change, together with distinctive common factors that may be applicable elsewhere.

Interaction with stakeholders and knowledge exchange will be a key part of our climate change activities. For example, interaction with policy-makers will continue through participation in appropriate strategy groups (e.g. SEERAD Climate Change and Agriculture Strategy Group, etc.), and with other stakeholders through activities such as one using agro-meteorological metrics with focus groups to stimulate debate on the nature of adaptations required by climate change.

We also plan to explore opportunities to extend this work internationally. For example, previous work by MI staff focused on the impacts of climate change on rice production and on mitigation of methane emissions from rice fields in Asia, but while a number of mitigation and adaptation strategies were identified, these studies tended to focus on individual aspects of rice agriculture, and did not consider to any great extent how they interact. Moreover, several of the CH_4 mitigation options examined involved a cost to the farmer, thus creating a 'social dilemma', in which individual interests of making a livelihood conflict with societal goals of reducing GHG emissions. These complex trade-offs are a common finding of first-generation climate change studies, and one which we aim to explore further through the integrated landscape-level approach.

References

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