## 12. Climate Change: Summary of Issues

**Problem**

It is now generally accepted that the increasing rate of greenhouse gas emissions during the twentieth century is forcing climate change. The most common greenhouse gases, carbon dioxide ($CO_2$), methane ($CH_4$) and nitrogen dioxide ($NO_2$), result from combustion of carbon fuels, agricultural practices and land use change. Scottish agriculture creates both carbon sources and carbon sinks. It is estimated that the Scottish agriculture and forestry sectors currently contribute about 5% of the UK total of greenhouse gas emissions. There is a significant opportunity for Scottish agriculture to play a key role in the Scottish Executive's contribution to the UK climate change mitigation strategies.

**Impact**

The current climate change scenario for Scotland to 2100 suggests:

- annual average warming of 2°-3°C.
- annual precipitation increasing by around 20% with precipitation intensities increasing in all seasons.
- changes in seasonal precipitation will vary from west to east. Summer rainfall will increase by up to 20% in the west, with a slight decrease in the east.
- there are likely to be up to 20 more "hot" days (>20°C) for each degree of global warming, and a general decrease in mean seasonal wind speeds.

Expert opinion suggests that these changes will not be the major drivers of agricultural change over the next century. However, climate change may have indirect effects on Scottish agriculture through, for example, impacts on world commodity supplies and effects on prices, impacts of trading in emissions, and the opportunities for Scottish agriculture to play a positive role in climate change mitigation strategies.

**Areas at risk**

There has been little research on the potential regional impacts of climate change on Scottish agriculture. Whilst the present change scenario is considered to be generally benign, evidence from studies on US agriculture indicate that there may be regional differences. Broadly:

1) Lengthening of growing season, increased temperatures and $CO_2$ levels will increase crop yields. These may reduce demands for crop land and reduce grazing pressure. This has a strong east/west component in Scotland.
2) Increased summer precipitation in the west will increase risks of soil damage through traffic and trampling effects. Reduced summer precipitation in the east may increase demands for irrigation water. Increased rainfall intensity will increase risk of soil erosion in vulnerable areas.
3) Increasing crop yields could lead to increases in nitrate leaching from crops and pastures.
4) The indeterminate effect of climate change or crop pests and diseases could mean increased use of pesticides and herbicides.

**Practical Actions**

Scottish agriculture can make a very positive contribution to the UK climate change mitigation strategy both directly and indirectly. Direct biological mitigation can be achieved by:

a) conservation of existing carbon pools eg through adoption of low impact, minimum tillage systems.
b) sequestration of carbon eg through diversification into biomass crops like short rotation coppice.
c) substitution of sustainably produced biological products (ie crops which have high energy conversion efficiencies and/or require little fossil fuel subsidy - a benefit of local food production). The "food miles" idea could be utilised to promote these crops.

Scottish agriculture can help mitigate the other impacts of climate change particularly in relation to flood risk and provision of wildlife corridors.

**Linkages**

Climate change will have systemic effects, impacting on all aspects of agriculture and the environment in Scotland.

**Research Gaps**

1) Assessment of the potential impacts of extreme events (eg individual events or successive seasons of "poor" weather).
2) Quantitative scenario analysis to assess potential regional effects (as per studies on US agriculture).
3) Cost-benefit analysis of the potential roles for Scottish agriculture in biological mitigation of climate change either through conservation, sequestration or substitution strategies.
4) Identification of the potential roles of agriculture in relation to mitigating other impacts (eg flooding and wildlife corridors) and examining how these can be factored into current land management strategies at farm or river catchment levels.

## 12. Climate Change: Critical Commentary

### 12.1. Introduction

The increasing rate of greenhouse gas (GHG) emissions throughout the twentieth century is now believed to be forcing climate change (IPCC Second Assessment Report, 1995). Scottish agriculture is both a source and a sink of greenhouse gases, and will itself be impacted by climate change both positively and negatively.

### 12.2. Policy Context

The UK is party to the United Nations Framework Convention on Climate Change. The third Conference of the Parties (COP-3) held at Kyoto in 1997 led to the Kyoto Protocol. Under this, the UK must reduce its baseline emissions of the 6 principal greenhouse gases to below the 1990 baseline of 216 MtC (million tonnes carbon equivalent). Agriculture, forestry and other land uses are thought to contribute about 12% (26 MtC) to the UK total greenhouse gas emissions (Table 12.1; Kerr *et al*., 1999). However, the category "Land-Use Change and Forestry" (LUCF) when related to Scotland accounts for 85% of the total UK LUCF emissions (Salway *et al*., 1999; Chapman *et al*., 2001). Whilst the proportions of the UK total greenhouse gas emissions from LUCF appears modest, the burden of responsibility for action in relation to mitigation of GHG emissions from soils will fall on Scottish agriculture. This disproportional effect relates to the preponderance of organic soils and peatlands in Scotland (Chapman *et al*., 2001).

Table 12.1. UK greenhouse gas emissions and likely changes by 2010 as a result of planned policies and actions (after Kerr *et al*., 1999 Table 1.3).

| **Sector** | **1990** | **2000** | **2010** | **% change 1990-2010** |
|---|---|---|---|---|
| Energy † | 72 | 55 | 59 | -18 |
| Business | 87 | 70 | 75 | -14 |
| Transport | 39 | 41 | 42 | +8 |
| Public | 10 | 9 | 9 | -10 |
| Agric, forestry and land use | 26 | 23 | 22 | -15 |
| TOTALS | 216 | 189 | 194 | -10 |
| $CO_2$ component | 168 | 157 | 163 | -3 |

† Some energy sector emissions are also allocated to the energy using sectors so the figures in the columns do not add up.

From the above it is clear that agriculture has a key role to play in the Scottish Executives contribution to the UK's climate change mitigation strategy. Biological mitigation can occur via 3 strategies: i) conservation of existing carbon pools; ii) sequestration by increasing the size of carbon pools; iii) substitution of sustainably produced biological products. Land use also has a role in mitigating other impacts of climate change (eg flooding). Nonetheless, it must be remembered that there is still a need for more accurate assessments of the carbon storage in the organic soils of Scotland, and the rates of carbon loss and accumulation under different land uses (Chapman *et al*., 2001).

### 12.3. Climate Change Scenarios

There is a wealth of scientific research on climate change. The principal actor internationally is the Intergovernmental Panel on Climate Change (IPCC) (www.ipcc.ch). Within the UK, much of the research is co-ordinated under the UK Climate Impacts Programme (UKCIP) (www.UKCIP.org.uk). This is co-ordinated through the Department for Environment, Food and Rural Affairs (DEFRA), and has had significant inputs from the Scottish Executive, through various regional studies principal amongst which have been:

i) Climate Change: Scottish Implications Scoping Study (Kerr *et al*., 1999)
ii) Climate Change: North Atlantic Comparison (Kerr and Allen, 2000)
iii) Climate Change and Changing Snowfall Patterns in Scotland (Harrison *et al*., 2001)
iv) Climate Change: Review of Levels of Protection Offered by Flood Protection Schemes (Price and McInally, 2001)
v) Potential Adaptations Strategies for Climate Change in Scotland (Kerr and McLeod, 2001)
vi) An Exploration of Regional Climate Change Scenarios for Scotland (Hulme *et al*., 2001)
vii) Review of the Contribution to Climate Change of Organic Soils Under Different Land Uses (Chapman *et al*., 2001)

Summaries and/or copies of these research reports can be found at the Scottish Executive Central Research Unit site (www.scotland.gov.uk/cru).

The Third Assessment Report (TAR) of the IPCC provides a summary of the observational evidence concerning changes in the Earth's atmosphere, climate and biophysical system (Table 12.2). Using 6 alternative future emissions scenarios, the IPCC has explored possible future changes in global climatic variables. It should be noted that the authors of the TAR recognise that it "does not achieve a fully integrated assessment of climate change because of the incomplete state of knowledge". Uncertainty is a key feature of all climate change modelling research (see section 12.4).

The key projections for global climate change provided by the IPCC TAR are:

- increase in globally averaged surface temperature of 0.4°C to 1.1°C (1990-2025); 0.8°C to 2.6°C (1990-2050); 1.4°C to 5.8°C (1990-2100) ie 2-10 times the central value of observed warming during the twentieth century.
- all land areas are likely to warm more than these global averages, particularly those at northern high latitudes in winter.
- globally averaged precipitation is projected to increase over the next 100 years with regional increases/decreases of the order of 5-20%

Table 12.2 20th century changes in the Earth's atmosphere, climate, and biophysical system[a] (after IPCC TAR, 2001)

| *Indicator* | *Observed Changes* |
|---|---|
| Atmosphere concentration of $CO_2$ | 280 ppm for the period 1000-1750 to 368 ppm in year 2000 (31±4% increase). |
| Terrestrial biospheric $CO_2$ exchange | Cumulative source of about 30 Gt C between the years 1800 and 2000; but during the 1990s, a net sink of about 14±7 Gt C. |
| Atmospheric concentration of $CH_4$ | 700 ppb for the period 1000-1750 to 1,750 ppb in year 2000 (151±25% increase). |
| Atmospheric concentration of $N_2O$ | 270 ppb for the period 1000-1750 to 316 ppb in year 2000 (17±5% increase). |
| Tropospheric concentration of $O_3$ | Increased by 35±15% from the years 1750 to 2000, varies with region. |
| Stratospheric concentration of $O_3$ | Decreased over the years 1970 to 2000, varies with altitude and latitude. |
| Atmospheric concentrations of HFCs, PFCs and $SF_6$ | Increased globally over the last 50 years. |
| Global mean surface temperature | Increased by 0.6±0.2°C over the 20th century; land areas warmed more than the oceans (very likely). |
| Northern Hemisphere surface temperature | Increased over the 20th century greater than during any other century in the last 1,000 years; 1990s warmed decade of the millennium (likely). |
| Diurnal surface temperature range | Decreased over the years 1950 to 2000 over land: night-time minimum temperatures increased at twice the rate of daytime maximum temperatures (likely). |
| Hot days/heat index | Increased (likely). |
| Cold/frost days | Decreased for nearly all land areas during the 20th century (very likely). |
| Continental precipitation | Increased by 5-10% over the 20th century in the Northern Hemisphere (very likely), although decreased in some regions (eg north and west Africa and parts of the Mediterranean). |
| Heavy precipitation events | Increased at mid- and high northern latitudes (likely). |
| Frequency and severity of drought | Increased summer drying and associated incidence of drought in a few areas (likely). In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades. |
| Global mean sea level | Increased at an average annual rate of 1 to 2mm during the 20th century. |
| Duration of ice cover of rivers and lakes | Decreased by about 2 weeks over the 20th century in mid- and high latitudes of the Northern Hemisphere (very likely). |
| Arctic sea-ice extent and thickness | Thinned by 40% in recent decades in late summer to early autumn (likely) and decreased in extent by 10-15% since the 1950s in spring and summer. |
| Non-polar glaciers | Widespread retreat during the 20th century. |
| Snow cover | Decreased in area by 10% since global observations became available from satellites in the 1960s (very likely). |
| Permafrost | Thawed, warmed and degraded in parts of the polar, sub-polar and mountainous regions. |
| El Niño events | Became more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years. |
| Growing season | Lengthened by about 1 to 4 days per decade during the last 40 years in the Northern Hemisphere, especially at higher latitudes. |
| Plant and animal ranges | Shifted poleward and up in elevation for plants, insects, birds and fish. |
| Breeding, flowering and migration | Earlier plant flowering, earlier bird arrival, earlier dates of breeding season, and earlier emergence of insects in the Northern Hemisphere. |
| Coral reef bleaching | Increased frequency, especially during El Niño events |
| Weather-related economic loss | Global inflation-adjusted losses rose an order of magnitude over the last 40 years (see Q2 Figure 2-7). Part of the observed upward trend is linked to socio-economic factors and part is linked to climatic factors. |

[a] This table provides examples of key observed changes and is not an exhaustive list. It includes both changes attributable to anthropogenic climate change and those that may be caused by natural variations or anthropogenic climate change. Confidence levels are reported where they are explicitly assessed by the relevant Working Group. An identical table in the Synthesis Report contains cross-references to the WGI and WGII reports.

NOTE: Where appropriate, the authors of the Third Assessment Report assigned confidence levels that represent their collective judgement in the validity of a conclusion based on observational evidence, modelling results, and theory that they have examined. The following words have been used throughout the text of the Synthesis Report to the TAR relating to WGI findings: virtually certain (greater than 99% chance that a result is true); very likely (90-99% chance); likely (66-90% chance); medium likelihood (33-60% chance); unlikely (10-33% chance); very unlikely (1-10% chance); and exceptionally unlikely (less than 1% chance). An explicit uncertainty range (±) is a likely range. Estimates of confidence relating to WGII findings are: very high (95% or greater), high (67-95%), medium (33-67%), low (5-33%), and very low (5% or less). No confidence levels were assigned in WGIII.

- precipitation is likely to increase over high-latitude regions in both summer and winter.
- cereal crop yields may increase with raised temperatures but high temperatures may reduce them.
- ability of livestock producers to adapt herds to changed climate stresses is poorly known.
- global warming may increase food prices globally and increase risk of hunger in vulnerable populations (see section 12.4 for alternative view).
- aggregated market sector effects (measured as changes in GDP) are mixed for developing countries. (Such estimates generally exclude effects of changes in climate variability and extremes).
- global potential for biological mitigation is around 100 GtC (cumulative) 2050. This is equivalent to 10-20% of the projected fossil fuel emissions.
- largest potential for biological mitigation is in the subtropical and tropical regions.
- the costs of mitigation per tonne of carbon are estimated at US$ 0.1-20 (tropical areas) US$ 20-100 (non-tropical).
- global modelling studies estimate national marginal costs to meet Kyoto targets as:
  US$ 20-600 per tC without trading
  US$ 15-150 per tC with Annex B trading.

These scenarios set the global context for UK climate change research. It should be noted that the economic assessments highlight both the relatively high costs of mitigation in non-tropical areas and the critical impact of trading in emissions.

One of the features of climate change research is that scenarios have limited shelf lives. Nonetheless, both the IPCC and the UKCIP share a set of common models. Principal amongst these is the Hadley Centre Regional global climate model. This model was used by the UKCIP98 scenario report and has a spatial resolution of 3.75° longitude by 2.5° latitude (approximately 350km x 250km for the UK). Scotland is in effect represented by one value for each meteorological variable for one average altitude (approx 220m). Whilst the next UKCIP scenario report (UKCIP02) will use the new Hadley Centre Regional Climate Model (HadRM3) which has a spatial resolution of 50km, Hulme *et al*. (2001) experimented with "downscaling" the UKCIP98 scenario for Scotland. Their work suggests the following may hold for Scotland to 2100:

- annual average warming of between 2° - 3°C with a small increase in warming with elevation in winter.
- year to year variations in the regional model for Scotland closely follow the global model for the majority of years, particularly as regards temperature.
- by 2080-2100 the coolest individual years are comparable with the hottest of recently observed years (eg 1990).
- annual precipitation will increase by around 20% with precipitation intensities increasing in all seasons.
- changes in summer precipitation vary from 20% increase in the west of Scotland to a slight reduction in the east.

- in terms of extreme daily weather there is likely to be around 18 more "hot" days (>20°C) for each degree of global warming, and a general decrease in mean seasonal wind speeds. (Note however that the UKCIP98 suggests a fluctuating pattern of changes in gale frequency over the UK - after Kerr *et al*., 1999).

Hulme *et al*. (2001) emphasise that their downscaling experiment was done using "one realisation of just one RCM driving by just one GCM forced with just one greenhouse gas forcing scenario" and the results must be "cautiously interpreted". Nonetheless, until the UKCIP02 scenarios are published later this year, the UKCIP98 scenarios as interpreted for Scotland by Kerr *et al. (*1999) and downscaled by Hulme *et al*. (2001) remain the current best estimates.

12.4. Potential Impacts on Agriculture

Much of the early research on the potential impacts of climate change on agriculture and forestry was done by Professor Martin Parry (1990). Most of the later research in the UK has involved desk-studies associated with the UKCIP, often involving expert knowledge. Kerr *et al*. (1999) suggest that "climate change in Scotland needs to be larger than projected over the next century for it to become the major driver in modifying agriculture" (p56). Nonetheless, they also acknowledge the difficulties of using process-based site models of crop growth to predict regional estimates of crop yields and variability, nor do we fully understand the impacts of climate extremes on agriculture production in Scotland.

Whilst recognising the issues relating to climate change in relation to crop pests and diseases, the general view is that a warmer climate in Scotland will assist in increasing the potential range of crops that can be grown and thus reduce commodity dependence. Whilst issues like increased incidence of flooding are recognised, it is perhaps surprising that the potential roles of agriculture and forestry in reducing future flood risk in Scotland are not highlighted.

The qualitative approach to assessing climate change impacts on agriculture in Scotland is to be contrasted to the highly quantitative approach adopted in the United States. This is exemplified by the work of the Agriculture Assessment Team reported by Reilly *et al*. (2000) (www.nacc.usgcrp.gov). They used what they call "end-to-end" analysis which links climate change scenarios derived from GCMs, with process-based crop yield models whose outputs are used as inputs to economic models for analysing the economic consequences of changed crop yields on farmers and consumers.

Because there is a lot of potential "read-across" from the study on US agriculture and Scottish agriculture, some of the key findings are summarised here. The work is predicated by the statement that US "producers see anything that might increase costs or limit their markets as a threat to their viability. Issues of concern include regulatory actions that might increase costs, such as efforts to control off-site consequences of soil erosion, agricultural chemicals, and livestock wastes; growing resistance to and restrictions on the use of genetically modified crops; new pests; and the development of pest resistance to existing pest-control strategies. Future changes in climate will interact with all of these factors" (Reilly et. al. 2000 p383).

1) yield changes for major crops

- benefits of increased precipitation outweigh the disbenefits of higher temperatures for dryland crops, whereas increased precipitation has little yield benefit in irrigated crops because water stress is not an issue.
- because yield models depend upon the general assumption that soil nutrients are not limiting, and pests, diseases and weeds pose no threats, the "positive crop responses to elevated $CO_2$ are responsible for one-third to one-half of the yield increases simulated" (p389)

2) economic impacts

- economic impacts were simulated using the US national agricultural sector model (ASM) linked to a global trade model.
- in general, the economic effects were positive reflecting the positive effects of climate change on US crop yields.
- foreign consumers gained in all the scenarios as a result of lower prices for US export commodities.

3) resources and environmental effects

- demand for land is likely to be reduced (cropland area down 5-10%; pasture areas down 10-15%).
- overall grazing pressure is reduced (reduction of 5-10% in Animal Unit Months).
- agricultural demand for water is forecast to reduce by up to 40% by 2090 but this may still cause problems in some areas (eg through excessive use or competing uses for groundwater).
- surface water quality is likely to be impacted by a 17-30% increase in nitrate loading associated with increased corn production to 2030.
- pesticide expenditures will generally increase on a crop by crop basis with between 10-20% increase for potatoes.

4) adaptation strategies

- farmers will need to adapt broadly to changing conditions in agriculture of which changing climate is only one factor (see also earlier conclusions from Kerr *et al*., 1999).
- possible adaptations directly linked to agriculture are:
    - sowing dates and other seasonal changes
    - new crop varieties
    - water supply, irrigation and drainage systems.

## 12.5. Research Gaps

It is clear from both the UK and US impacts research that no assessment adequately includes the potential impacts of extreme events. These could be individual flood, drought or heatwaves, or successive years of poor weather (see for example work of

Hudson & Birnie, 2000). Increased incidences of pests and diseases may induce similar effects. In general, all the impacts research rests on assumptions of linearity in change processes. This assumption may or may not be justified and it might be valuable to question it further, possibly via formal risk analysis.

In general terms, the existing research suggests that climate change does not represent a significant threat to agriculture in Scotland. There is however a need to:

i) Approach the analysis of impacts with the same rigour as exemplified in the US study.
ii) Examine both the negative and the positive effects under different socio-ecological scenarios (already part of UKCIP).
iii) Identify much more clearly the potential role for Scottish agriculture in biological mitigation (see for example Smith *et al*., 2001).
    a) conservation of existing carbon pools eg through adoption of low impact, minimum tillage systems.
    b) sequestration of carbon eg through increasing use of energy cropping like short rotation coppice.
    c) substitution of sustainably produced biological products.
iv) Identify the possible roles of agriculture and forestry in mitigating the other impacts of climate change, particularly in relation to flooding and natural heritage impacts (eg through provision of wildlife corridors).

12.6. <u>References</u>

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Smith, P. *et al*. (2001). Enhancing the carbon sink in European agricultural soils: including trace gas fluxes in estimates of carbon mitigation potential. *Nutrient Cycling in Agroecosystems,* **60**(1-3), 237-252.

* all available from www.scotland.gov.uk/cru

IPCC 2001. Climate Change 2001: Synthesis Report (www.ipcc.ch/pub)

## 12.7. Web Sites

| | |
|---|---|
| Environment Canada | www.ec.gc.ca/climate/index.html |
| Global Warming Early Warning Signs | www.climatehotmap.org |
| Intergovernmental Panel on Climate Change (IPCC) | www.ipcc.ch |
| IPCC | www.usgcrp.gov/ipcc |
| IPCC Data Distribution Centre | http://ipcc-ddc.cru.uea.ac.uk/ |
| Scottish Executive Central Research Unit | www.scotland.gov.uk/cru |
| The Pew Center on Global Climate Change | www.pewclimate.org |
| UK Climate Impacts Programme (UKCIP) | www.ukcip.org.uk |
| United National Framework Convention on Climate Change (UNFCCC) | www.unfccc.de |
| US Global Change Research Information Office | www.gcrio.org |
| US Global Change Research Program | www.usgcrp.gov/usgcrp/new.htm |
| US National Assessment | www.nacc.usgcrp.gov |

**Please see Appendix 7 for selected bibliography on climate change**