mate change. These projections are made using the climate projections and the biophysical models selected for the study (as described in Section 3.2.2.1). Because all changes in environmental conditions not due to climate factors should already have been incorporated in the development of the environmental trends in the absence of climate change, the only changes in the trends to be incorporated here are those due solely to climate change.

Future changes in climate can be expected to modify some of the environmental trends outlined in Section 3.4.3. Furthermore, there are likely to be a set of additional environmental changes that are directly related to the changes in climate themselves. The two factors most commonly required in assessments are greenhouse gas concentrations and sea level rise.

Projections of greenhouse gas concentrations are important for assessing effects, *inter alia*, on radiative forcing of the climate, on depletion of stratospheric ozone (e.g., CFCs) and on plant response (e.g., CO_2 and tropospheric ozone). In applying them, however, they should be consistent with the projected climate changes (see Section 3.4.2.2, above).

Sea level rise is one of the major impacts projected under global warming. Global factors such as the rate of warming, expansion of sea water, and melting of ice sheets and glaciers all contribute to this effect. However, local conditions such as coastal land subsidence should also be taken into account in considering regional impacts. In most assessments, the vulnerability of a study region to the effects of sea level rise will be apparent (e.g., in low lying coastal zones). However, some inland locations may be also be affected (for example, through saline incursion of groundwater). The magnitude of future sea level rise is still under discussion, but the estimates reported by the IPCC may serve as a useful basis for constructing scenarios (IPCC, 1990a). Again, these should be consistent with projected changes in climate, and it should be noted that they are projected to vary regionally as well as temporally.

Other factors that are directly affected by climate include river flow, run-off, soil characteristics, erosion and water quality. Projections of these often require full impact assessments of their own, or could be included as interactive components within an integrated assessment framework (see Section 3.2.2.3).

3.4.7 Projecting socio-economic trends with climate change

The changes in environmental conditions that are attributable solely to climate change serve as inputs to economic models that project the changes in socio-economic conditions due to climate change over the study period. All other changes in socio-economic conditions over the period of analysis are attributable to non-climatic factors and should have been included in the estimation of socio-economic changes in the absence of climate change.

Socio-economic factors that influence the exposure unit may themselves be sensitive to climate change, so the effects of climate should be included in projections of those. In some cases this may not be feasible (e.g., it is not known how climate change might affect population growth) and trends estimated in the absence of climate change would probably suffice (see Section 3.4.4). In other cases, projections can be adjusted to accommodate possible effects of climate (e.g., future winter electricity demand may be reduced relative to trend due to climate warming).

Finally, many human responses to climate change are predictable enough to be factored in to future projections. These are often accounted for in model simulations as feedbacks or 'automatic adjustments' to climate change. For example, as the climate changes, the growing season for crop plants would also change, and crop performance might be improved by shifting the sowing date. In some crop growth models the sowing date is determined by climate (e.g., the start of the rainy season), so it would be altered automatically to suit the conditions. Here, the model is performing internally an adjustment that a farmer might do instinctively.

3.5 Assessment of Impacts

Impacts are estimated as the differences over the study period between the environmental and socio-economic conditions projected to exist without climate change and those that are projected with climate change. The impacts provide the basis for the assessment.

The evaluation of results obtained in an assessment is likely to be influenced in part by the approach employed, and in part by the required outputs from the research. Some of the more commonly applied techniques of evaluation are described below.

3.5.1 Qualitative description

An evaluation may rely solely on qualitative or semi-quantitative assessments, in which case qualitative description is the common method of presenting the findings. The success of such evaluations usually rests on the experience and interpretative skills of the analyst, particularly concerning projections of possible future impacts of climate. The disadvantages of subjectivity in this have to be weighed against the ability to consider all factors thought to be of importance (something that is not always possible using more objective methods such as modelling).

3.5.2 Indicators of change

A potentially useful method of evaluating both the impacts of climate change and the changes themselves is to focus on regions, organisms or activities that are intrinsically sensitive to climate. For example, long-term changes in the average timing of phenological stages in hardy, well-adapted natural plant species might suggest a general warming of the climate. Moreover, changes in plant behaviour may indicate that certain critical thresholds of temperature change have been approached or exceeded. For instance, an increasing frequency of events where plants fail to flower may suggest that the chilling (vernalization) requirements of the plant have not been fulfilled. Another example is low lying coastal zones at risk from inundation, and the vulnerable populations located in such regions.

3.5.3 Compliance to standards

Some impacts may be characterized by the ability to meet certain standards which have been enforced by law. The standards thus provide a reference or an objective against which to measure the impacts of climate change. For example, the effect of climate change on water quality could be gauged by reference to current water quality standards.

3.5.4 Costs and benefits

Perhaps the most valuable results that can be provided to policy makers by impact assessments are those which express impacts as potential costs or benefits. Methods of evaluating these range from formal economic techniques such as cost-benefit analysis to descriptive or qualitative assessments.

Cost-benefit analysis is often employed to assess the most efficient allocation of resources (see Box 5). This is achieved through the balancing or optimization of various costs and benefits anticipated in undertaking a new project or implementing a new policy, accounting for the reallocation of resources likely to be brought about by external influences such as climatic change. The approach makes explicit the expectation that a change in resource allocation is likely to yield benefits as well as costs, a useful counterpoint to many climate impact studies, where negative impacts have tended to receive the greatest attention. In addition, such an approach can examine the 'waiting cost' of doing nothing to mitigate future climate change, and the 'unexpected cost' of surprise events.

Whatever measures are employed to assess costs and benefits, they should employ a common metric. Thus, for example, where monetary values are ascribed, this should be calculated in terms of net present value. The choice of discount rate used to calculate present value will vary from nation to nation depending on factors such as the level of economic development and on social provision. Moreover, the depreciation of capital assets with time, which also varies from country to country, should be explicitly considered in the calculations.

One of the issues in formal cost-benefit analysis is whether, and how, to assign a single metric for all costs and benefits. For example, climatic warming may offer tangible benefits through reducing winter heating bills. However, it may also lead to the disappearance of a rare species adapted to a cooler climate, the cost of which is difficult to assess. These types of consideration have led to the emergence of a new discipline, environmental economics. This seeks to assign quantitative worth to environmental resources that traditionally have been regarded as 'global commons', such as air, water and soil, so that they can be balanced against other more tangible, quantitative measures of worth (e.g., see Barbier and Pearce, 1990).

There are also social costs and benefits that are difficult to assess in economic terms. Alternative quantitative measures do exist for some of these (e.g., for quality of life or social equity), but others have to be considered in purely descriptive terms (for example, aesthetic preferences, psychological effects).

3.5.5 Geographical analysis

One common feature of the different approaches to climate impact assessment is that they all have a geographical dimension. Climate and its impacts vary over space, and this pattern of variation is likely to change as the climate changes. These aspects are of crucial importance for policy-makers operating at regional, national or international scale, because changes in resource patterns may affect regional equity, with consequent implications for planning.

Thus the geographical analysis of climatic changes and their impacts, where results are presented as maps, has received growing attention in recent years. This trend has been paralleled by the rapid development of computer-based geographical information systems (GIS), which can be used to store, analyse, merge and depict spatial information.

The applications of GIS in climate impact analysis include:

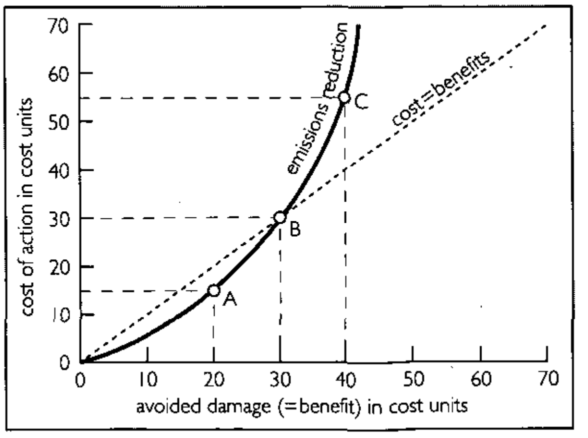
- Depicting patterns of climate (past, present or projected).
- Using simple indices to evaluate the present-day regional potential for different activities based on climate and other

BOX 5
COST-BENEFIT ANALYSIS

Cost-benefit analysis has the specific objective of evaluating an anticipated decision or range of decision responses. For example, in considering the costs and benefits of reducing greenhouse gas emissions, a cost-benefit analysis might seek to evaluate a question facing a decision maker: 'Do the benefits of reducing emissions by 20 percent outweigh the costs of doing so?' The benefits of this action are the avoided damages (i.e., costs) of climate change due to GHG emissions (evaluated, for instance, using models of the type described in Section 3.2.2). Hence, if it is estimated that the costs of climate change were 100 units and a 30 percent reduction in emissions would limit climate change enough so that 20 percent of the costs (damages) are avoided, then the benefit of reducing emissions would be 20 units. If the cost of this 30 percent emissions reduction was estimated to be 15 units then it would be concluded that the cost-benefit ratio of the action was favourable because the benefits (20 units) were greater than the costs (15 units) (Point A in Figure).

Economic analysis generally concludes that the optimal result is where the marginal cost and marginal benefit of the change are equal. In the example, this occurs at 30 cost units, where the cost of reducing a further kilogram of emissions is just equal to the avoided damage due to that extra kilogram (Point B in Figure). Further emissions reduction beyond this point produces an unfavourable cost-benefit ratio (e.g., an emissions reduction of 45 percent costing 55 units has a benefit in avoided damage of only 40 units—Point C in Figure).

Note, in addition, that it may not be physically possible to remove the full costs of climate change, as no emission policies are capable of fully stabilising GHG-concentrations. Thus, only a proportion of the estimated costs due to climate change can be avoided, serving as a limiting condition in the cost-benefit evaluation. Of course, there may also be benefits of climate change or non-climatic benefits of actions that limit climate change. These become costs in a cost-benefit analysis, because they are benefits that will be diminished or lost if climate change is reduced.



environmental factors (e.g., crop suitability, energy demand, recreation, water resources). The indices can then be compared with observed patterns of each activity as a validation test.

- Mapping changes in the pattern of potential induced by a given change in climate. In this way the extent and rate of shift in zones of potential can be evaluated for a given change in climate.
- Identifying regions of particular sensitivity to climate, which may merit more detailed examination (for example, regions where, on the basis of the map analysis, it may be possible, under a changed climate, to introduce new crop species).
- Considering impacts on different activities within the same geographical region, so as to provide a compatible framework for comparison and evaluation (e.g., to consider the likely competing pressures on land use from agriculture, recreation, conservation and forestry under a changed climate).

A simple ecological example is given in Box 6. As computer power improves, the feasibility of conducting detailed modelling studies at a regional scale has been enhanced. The main constraint is on the availability of detailed data over large areas, but sophisticated statistical interpolation techniques and the application of stochastic weather generators to provide artificial data at a high time resolution, may offer partial solutions.

3.5.6 Dealing with uncertainty

Uncertainties pervade all levels of a climate impact assessment, including the projection of future GHG emissions, atmospheric GHG concentrations, changes in climate, their potential impacts and the evaluation of adjustments. There are two methods which attempt to account for these uncertainties: scenario analysis and risk analysis.

3.5.6.1 Scenario analysis

Scenario analysis comprises a set of techniques for anticipating and preparing for the impacts of uncertain future events. It is

BOX 6
CASE STUDY: EFFECTS OF CLIMATE CHANGE ON NATURAL TERRESTRIAL ECOSYSTEMS IN NORWAY

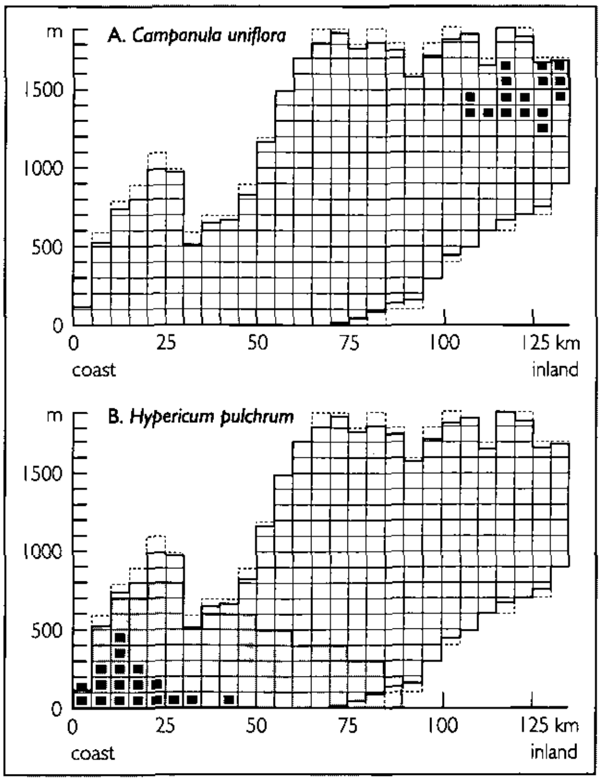
Problem. The objectives of this assessment were to examine the probable patterns of ecological change in Norway under a changed climate regime, with a particular emphasis on identifying plant species and communities sensitive to or at risk from climate change.

Methods. In part descriptive, based on expert judgement, and in part using correlative models of species distribution. All methods examined the potential impacts of climate change as defined in a specific climatic scenario for Norway.

Testing of methods/sensitivity. Correlative models are based on the spatial coincidence of vegetation species and climatic variables under present-day climate. They are very simple to apply, but have the disadvantage that they do not provide an ecophysiological explanation of the observed plant distributions, although they usually represent hypotheses about which factors control or limit those distributions. The models can really only be tested against palaeoecological evidence of plant distributions from previous cool or warm periods, where the contemporary climatic information is derived from independent sources (e.g., insect evidence).

Scenarios. A seasonal scenario for a doubling of CO_2 was used, based on a subjective composite of results from several GCMs for the Norwegian region.

Impacts. The effects of climate change on species distribution were estimated using a vertical transect through central Norway, giving altitude on the vertical axis and distance from the Atlantic coast on the horizontal axis. Figures A and B illustrate the sensitivity of two species: *Campanula uniflora* (a rare



Source: Holten and Carey (1992)

Alpine and continental species) and *Hypericum pulchrum* (a frost sensitive coastal species) to the climate changes described by the scenario. Solid squares indicate the current and shaded squares the predicted distribution of a species. The analysis suggests that rare northern or Alpine species may be threatened by extinction (Figure A), both due to shifts in climate and to changes in snow cover and runoff. Temperate and oceanic zone species would be favoured under the changed climatic regime (Figure B), but their colonization could be delayed by anthropogenic or natural barriers.