Downscaling scenarios to local landscapes: a case study of the Norfolk Broads

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Abstract

Our ability to analyse, forecast, and model future changes in policy and the environment has improved dramatically in the last few decades. However, there still remain large uncertainties in predicting likely changes. Scenarios and land cover data are often used as tools for investigating possible futures. Yet, a number of factors may limit scenario application within local landscapes, particularly with regard to coarse spatial resolution and inapplicability of scenario narratives at such fine scales. This study applies coarse resolution scenarios and land use datasets, via a process of downscaling, to local landscapes and explores some of the consequences for biodiversity. It provides input into local landscape management and decision-making. The study focuses on the Norfolk Broads, an internationally important wetland in the UK.

Landscape characterisation data is incorporated to provide localised drivers of change whilst existing scenarios and land cover datasets are utilised to help translate these localised drivers of change to individual land parcels. Using a Geographic Information System (GIS) methodology, land cover change data from the RegIS scenario-based project is downscaled to the study area to the year 2100. The output is a set of localised scenarios and narratives that describes the reaction of the area to national and regional-scale drivers. Results suggest that the downscaling methodology developed here provides a means of producing landscape data which are of high spatial resolution from coarse input data, and hence may form an important input into landscape planning and management processes.

In order to illustrate an application of the localised land cover data, two contrasting management scenarios are developed for two important breeding wader species and land parcels delineated which may provide suitable habitat. Estimates are also made regarding the population densities that these suitable areas could sustain and the contribution of these populations to UK conservation targets. The methodology presented here provides an alternative procedure to help identify areas of conservation opportunity and provides input into local decision-making processes.

In the final chapter, the utility of the downscaling approach developed in this study is evaluated in the context of local land use management planning to provide feedback into the current policy mix. Informal interviews are undertaken with a range of stakeholders, and the opportunities and barriers to the implementation of the methodology presented in the thesis are explored.

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Declaration

The research reported is my own original work which was carried out in collaboration with others as follows:

Chapter 1 was written by Paul Munday.

Chapter 2 – Paul Munday was the lead author on a paper in review as:

> Munday P and Jones A (In review) A framework for developing high-resolution scenarios at the landscape-scale: the Norfolk Broads. *Environment and Planning B: Planning and Design.*
>
> Paul reviewed the literature, designed the framework, undertook GIS analyses and wrote the manuscript. Andy Jones contributed to and advised on the design of the framework and reviewed drafts of the manuscript.

Chapter 3 – Paul Munday was the lead author on a paper published as:

> Munday P, Jones A P and Lovett A A 2010 Utilising scenarios to facilitate multi-objective land use modelling for Broadland, UK, to 2100. *Transactions in GIS* 14 (3): 241-263
>
> Paul reviewed the literature, designed the framework, undertook GIS analyses and wrote the manuscript. Andy Jones and Andrew Lovett contributed to and advised on the design of the framework and GIS analyses and reviewed drafts of the manuscript.

Chapter 4 – Paul Munday was the lead author on a paper in review as:

> Munday P, Jones A and Lovett A A (In review) Identifying conservation opportunities under future land use scenarios: a case study of *Tringa totanus* and *Botaurus stellaris.*
>
> Paul reviewed the literature, designed the framework, undertook GIS analyses and wrote the manuscript. Andy Jones and Andrew Lovett contributed to and advised on the design of the framework and GIS analyses and reviewed drafts of the manuscript.

Chapter 5 – Paul was the lead author on the paper. Andy Jones contributed and advised on drafts of the manuscript.

Chapter 6 was written by Paul Munday.

Chapter 7 was written by Paul Munday.

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Chapter 1

Introduction

1. Introduction

Intense curiosity has always been a motivating force for acquiring knowledge. In the past, naturalists explored woodlands, fields and mountains, documenting and collecting varieties of flora and fauna. This led to more systematic methods of recording information which were realised in the environmental disciplines of botany, geology and ecology amongst others (Alcamo, 2008). Whilst these methods of collecting and evaluating environmental data have allowed us to gain greater knowledge of our current and past environments, the same approaches may not be applied to investigate potential futures. Indeed, more recently, many of the questions posed by scientists and societies today focus upon future states of the environment, including, the identification of driving forces which are most likely to influence the dynamics of environmental systems (Lambin et al. 2001) and discussion of policies which might mitigate future environmental problems (Leiserowitz, 2006; Payne et al. 2004). Consequently, one may question the catalyst that has prompted recent consideration of futures in environmental decision-making given our focus upon reconstructing events that happened in the past.

Discussion in this introduction primarily focuses upon establishing the foundations of futures research alongside the need and the emerging role of scenarios as a tool in environmental decision-making. Next, rationale and motivation for the research project presented in this thesis is given followed by aims and objectives. Finally, an outline of the thesis chapters is provided.

1.1. The foundations for futures research, scenarios and their role in decision-making

The central function of futures research aims not to predict what a future or the future will be, but to explore various alternative future states that result as a product of our collective actions and choices (McHale, 1975). Futures research is typically defined as the process of investigating possible futures using a range of tools including mathematical models and expert judgement (Fowles, 1978). The evolution of futures research did not develop in a linear way but was influenced by a number of influential bodies, namely the RAND Corporation, Stanford Research Institute, Shell, SEMA Metra Consulting Group and many others (Berkhout et al. 2002). It has been suggested that futures research has its foundations in the 1940s, whereby multiple options were produced and compared by the US military to inform strategic decisions and to facilitate more efficient responses to potential threats (Chermack et al. 2001). During the 1960s, Kahn and Wiener (1963) afforded close attention to the development of stories to help individuals consider the ‘unthinkable’ in the event of an extreme future event, such as nuclear war, and to encourage better preparedness. In addition, at around the same time, futures research became more widespread throughout business and governments as tools for strategic planning, for example, to aid identification of potential market opportunities and to reduce risks associated with investment (Schoemaker, 1995).

It has been suggested that the increased popularity of futures research amongst businesses and governments was due to a sense of decreased stability associated with economic, technological and political systems at the time (Chermack, 2001). This instability was likely borne out of the sensitivity of such systems to sudden changes, such as that instigated by the assassinations of influential political figures including Martin Luther King Jr. and President John F. Kennedy (see Iqbal and Zorn, 2008) and also environmental disasters such as Hurricane Betsy ('the first billion dollar hurricane' – see Burby, 2006) (de Jouvenel, 1967).

During the 1970s, renewed interest was placed upon futures research. This took the form of scenario planning, particularly by businesses and corporations who wanted to develop protocols for dealing with the consequences of unstable market conditions and who recognised the benefits of being able to react promptly to opportunities as and when they developed (Schoemaker, 1995; Berkhout et al. 2002). An example is Royal Dutch/Shell who were particularly strong proponents of scenarios.

Although definitions tend to vary depending upon how scenarios are utilised, they may be collectively defined as representations of coherent, credible stories about alternative futures (Chermack et al. 2001). Importantly, they are intended to not represent forecasts or preferences of the future (Schwartz, 1991). Royal Dutch/Shell utilised scenarios in this format as part of a process for generating and evaluating its strategic options (Schoemaker, 1995). As a result, the company were able to plan many years ahead of its competitors. Indeed, following falling oil prices in the 1970s as a result of the Yom Kippur war, Shell swiftly reacted to market conditions and reduced supply, enabling market prices to rise (Chermack et al. 2001). The ability to act quickly has been credited as the primary reason behind the company's lead in the oil industry (van der Heijden, 1997).

Disillusionment with scenario planning during the 1980s and a major recession led to a decline in their use. It has been suggested that planners tended to over simplify the use of scenarios, whereby they confused the nature of storytelling with forecasting (Ringland, 1998; Godet and Roubelat, 1996). However, rising public awareness of the impacts of environmental degradation during the 1980s, influenced by the spread of environmentalist parties throughout Europe and environmental disasters such as Exxon Valdez oil spill (see Peterson et al. 2003) and the eruption of Mount St. Helens (see Dale et al. 2005), facilitated increased support amongst researchers for the use of scenarios in environmental decision-making (Inglehart, 1995). Indeed, an important question posed by many researchers at the time centred upon societies' ability to make sound and representative decisions in light of unexpected environmental change, or the occurrence of natural disasters (Tonn et al. 1999). Consequently, it was recognised that scenarios were potentially a useful, yet under-utilised, tool available to decision-makers as they were able to offer solutions to complex issues for which there appeared to be no simple answers (Davis, 2002).

1.2. The emerging importance of scenarios in environmental decision-making

In recent times, scenarios have been utilised in a variety of contexts, perhaps most prominently for the purpose of environmental decision-making (Berkhout et al. 2002). For example in the 1990s, scenarios comprising estimates of future ozone depletion in the upper atmosphere were generated which suggested that not only would deterioration likely continue, but also that deterioration may be reversed if harmful emissions of ozone-depleting chlorofluorocarbons (CFCs) were reduced (Alcamo, 2008). Such scenarios allowed environmental decision-makers to formulate appropriate policies to reduce the use of CFCs as refrigerants and propellants in aerosols as part of European Union legislation. As a result, international ratification of the Montreal Protocol followed in 1997 and is now widely accepted as reversing levels of stratospheric ozone (Rounsevell et al. 2002). Due to its resounding success, the Montreal Protocol is credited as being the most important example of environmental legislation to date and scenarios are credited as playing a key role in this process (Benedick, 1998).

Over the last decade, a more significant example of the need for scenarios is in the investigation of future climatic and socio-economic change. Although it is acknowledged that it is not possible to predict the future with a high degree of certainty, a solution adopted by many researchers has been to explore what might happen given certain assumptions about societal developments and environmental changes (Rounsevell et al. 2005). Such explorations are particularly useful to decision-makers given the sensitivity to change of economic, social and environmental systems described. In recognition of this sensitivity, an increasing volume of literature has been produced around discussion of future states of the environment. Some of this work comprises modelled results of future climate developed in a Geographic Information System (GIS) and includes strategies for adaptation and mitigation (see Easterling et al. 2007; Wilbanks et al. 2007).

Most widely utilised are those scenarios developed by the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (hereafter IPCC SRES - IPCC, 2000) which reflect varying levels of economic and social development and environmental change. Scenarios in this sense have been utilised in a variety of sciences (physical, economic and social), in varied circumstances and for different purposes (Carter et al. 2001). Consequently, our need to investigate possible futures now encompasses all manner of decision-making, including the comparison of different ecological management regimes (Klenner et al. 2000), identification of conservation areas (Myers et al. 2000) and input into land use planning and management processes (Xiang and Clarke, 2003).

Given the likelihood of increasing climatic and socio-economic pressures upon economic, social and environmental systems, an area in which the further development and application of scenarios is particularly valuable is the evaluation of landscape change. The following section discusses the rationale and motivation for the research project presented in this thesis, including the need for scenarios in the investigation of future landscape change and problems associated with translating existing scenarios to local-scales.

1.3. Rationale and motivation

The value of landscape is immeasurable. Landscapes provide a plethora of services that satisfy a range of needs, for example, spiritual fulfilment and aesthetic enjoyment, education and experience and by means of reflecting cultural identity. We value landscapes because of their intrinsic charm, their contribution to our national identity and local distinctiveness, their artistic inspiration and for the goods and services that they provide (Forman, 1995; Natural England, 2010).

In addition to their societal roles, landscapes support a range of human activities. These include industry, residency and tourism and recreation. Such activities impart a variety of pressures, in particular, aggregate removal, water abstraction and agricultural intensification (Bürgi et al. 2004). At the same time, these pressures have resulted in loss of biotic diversity, habitat fragmentation and homogenisation of landscapes via changes in land use and land cover (Sala et al. 2000; Millennium Ecosystem Assessment, 2005). As a result of these interactions, landscapes can be considered to be the primary setting where the combined effects of society and nature become visible (Forman, 1995). In that respect, landscapes may be likened to canvases which document historical change.

Whilst landscapes have responded over time to a variety of pressures it is predicted that future changes, driven by climate and socio-economic interactions, will place ever-increasing demands upon landscapes. For example, socio-economic pressures, including development of the built environment and rising populations, are likely to result in increasing urbanisation and changes in land cover (Millennium Ecosystem Assessment, 2005). Indeed, it has been suggested that by the year 2030 global population is likely to rise by as much as 30 %, coupled with increases in per capita wealth throughout many Western societies, and also in the developing world (United Nations, 2004;

Wilbanks et al. 2007). This is likely to place an even greater pressure upon landscapes by way of increasing tourism and recreation, but also via pollution and land degradation. In addition, climatic changes, particularly rising temperatures, are likely to drive shifts in species' ranges, reduce the productivity of crops and negatively impact upon landscape biodiversity (Fischlin et al. 2007; Easterling et al. 2007). Other climatic changes are expected to reinforce the consequences of socio-economic pressures, for example, via increased flood and drought frequency, reduced summer rainfall and sea level rise (IPCC, 2007).

Although the changes described will inevitably impact landscapes in general, it is likely that their effects will be even more apparent within environments particularly sensitive to change. An example is wetlands, where even small changes may dramatically alter the landscapes that we see today and the unique flora and fauna that they support (IPCC, 2001). Wetlands cover approximately 6 % of the Earth's land surface (Organisation for Economic Aid and Development, 1996) and are important landscapes due to their ability to provide protection against flooding and to store flood waters. They also help to purify our waters and offer biodiversity-rich habitat to a range of important species (Woodward and Wui, 2001).

Coupled with their ecological importance, wetlands are amongst some of the most economically valuable habitats due to the range of ecosystem services that they provide (Heimlich et al. 1998). Indeed, evidence suggests that the value of a single hectare of wetland can be as high as £24,100 ha^{-1} yr^{-1}; nearly double that of forest or six times that of grassland ecosystems (Constanza et al. 1997; Heimlich et al. 1998). However, over the last century, around half of the world's wetland landscapes have been lost (Dugan, 1993) and wetlands are now amongst the most degraded of all landscapes (Amezaga et al. 2002). Losses have been attributed to socio-economic pressures, for example widespread land drainage for conversion to agriculture for the purpose of increasing areas available for grazing and for growing crops (Millennium Ecosystem Assessment, 2005). Pollution and environmental changes, including rising sea levels due to climate change, are also cited as important drivers of landscape change (IPCC, 2007). Consequently, it is likely that sensitive landscapes like wetlands may experience greater pressures from future climatic and socio-economic changes. There is therefore a growing need to focus efforts upon investigating potential change within these sensitive localities.

Despite the inherent uncertainties in predicting the precise impacts of changes that may occur, decision-makers must still make choices which may influence how landscapes alter and are used in the future. In order to assist these decisions, a number of scenarios are available for application within landscapes at a variety of spatial scales. Examples include European e.g. IPCC SRES at approximately 2.5° x 2.5° (*c.* 250 x 250 km) (IPCC, 2000); national e.g. UKCIP at 50 km x 50 km resolution (Hulme and Jenkins, 1998; Hulme et al. 2002) and regional e.g. RegIS at 5 km x 5 km (Regional Climate Impact Studies in East Anglia and North West England – Holman and Loveland, 2002) projects. These projects often output scenarios in qualitative (e.g. storylines or narratives) and quantitative (e.g. land use or land cover data) datasets which are potentially of use to studies which investigate the impacts of future climatic and socio-economic change upon landscapes. Nevertheless, at even the 5 km gridscale scenarios may often be too crude a resolution for application at local-scales where understanding of the likely changes at the land parcel level is commonly required (e.g. by land managers, such as farmers, and/or environmental planners). For the purposes of this work, coarse spatial resolution refers to scenarios with spatial resolutions greater than the regional-scale. Due to their relatively coarse spatial resolution, a method for downscaling existing scenarios to the local-scale is needed in order that we are able to better understand the impacts of future change upon sensitive landscapes, such as wetlands. This may then feedback into current decision-making to improve understanding of the impacts of decisions that we make today.

Therefore, the production of a methodology which downscales coarser-resolution scenarios is the aim of this thesis and is illustrated using a case study of the Norfolk Broads.

1.4. Study site – The Norfolk Broads (Broadland)

The Norfolk Broads (Broadland – Figure 1.1) lies in eastern England within the counties of Norfolk and Suffolk. The region comprises numerous areas of grazing marshes, fen, woodland and intensive arable lands. The Broads themselves are man-made shallow lakes, typically fringed by fen and reedbeds with associated parcels of Carr woodland. The area forms one of the largest networks of wetlands in the UK, and is unique in Europe in terms of ecology and landscape.

Broadland was an ideal site for this study as it has become the epitome of how people impinge on natural systems, at first enhancing them, in the sense of creating variety, and more recently pressurising them as a result of economic and cultural changes (Moss, 2001). Pressures for change imparted by tourism and recreation, declining markets for traditional products such as reed and sedge, and climate change, are expected to place the landscape under even greater pressures in the future.

On 16th December, 2006, a stakeholder mapping exercise was undertaken to ascertain the drivers, or pressures of change, affecting Broadland and those likely to impact the area in the future, alongside the types of stakeholder who might utilise downscaled scenarios. In total, five individuals were consulted from organisations having a direct influence upon the Broadland landscape, these comprised stakeholders from the Broads Authority, Natural England, Broadland Environmental Services Ltd, the Royal Society for the Protection of Birds (RSPB) and the Norfolk Wildlife Trust.

During the exercise, a wide range of drivers were identified as imparting pressures upon Broadland, and in some cases providing opportunities, both at present and in the future. Many of these drivers had previously been described in current policy documents and strategies governing the area (e.g. the Broads Plan, 2007a). These included international legislation such as the Habitats and Birds Directives (European Union, 1979, 1992) which require the authority to achieve favourable conservation status of habitats and species of European importance, and the Water Framework Directive (hereafter WFD – European Union, 2000) which was suggested as placing increasing pressures upon the authority to achieve good status of water bodies by 2015. In light of future pressures upon water availability and quality, due to increased abstraction and diffuse source pollution, these international policy tools were likely to be particularly challenging drivers of change within Broadland over the coming years.

At the national-scale, the presence of policies and initiatives such as the Broads Environmentally Sensitive Area (ESA) scheme (now superseded by DEFRA's Environmental Stewardship scheme comprising Entry Level Stewardship and Higher Level Stewardship) and the Countryside and Rights of Way Act (CROW) were suggested as elements likely to impart pressures through management and restoration plans governing protected sites, for example Sites of Special Scientific Interest (SSSIs) and Special Protection Areas (SPAs). It was suggested that these schemes were key to maintaining the current grazing marsh landscape, and for enhancing biodiversity, due to the large land areas that these schemes covered (approximately 43,000 ha in the case of ESA). Achieving habitats and species targets of the UK Biodiversity Action Plan were also highlighted as presenting both a challenge and opportunity to stakeholders in the sense of identifying suitable areas of habitat to accommodate existing and new species of flora and fauna, and associated pressures of meeting proposed targets were likely to further complicate the management task. Perhaps most prominently, agricultural policy and support mechanisms to farmers were highlighted as particularly important drivers of change within the region over short to medium-timescales (i.e. 5-15 years). Specifically, stakeholders raised concerns regarding changes to the European Union's Common Agricultural Policy (CAP) due in 2013 (Buckwell, 2008; DEFRA, 2010) that may directly impact nature conservation efforts and stimulate uncertainty and diversification within the local farming economy.

Over longer timescales, stakeholders highlighted a number of more general drivers likely to impact the Broadland landscape; these included social values, the growth of the global economy and environmental change specifically that related to climate. It was suggested that the impacts of future population growth, particularly within rural areas as people become increasingly able to work from home due to teleworking and improved internet access, were likely to place increasing pressures upon housing and built infrastructure, such as roads and railways. It was also suggested that farmers may face pressures to become more sustainable and to diversify production into non-native crops due to rising temperatures and an increase in grazing due to threats posed by flood risk. With regard to environmental change, stakeholders suggested that climate change may provide opportunities for wetland creation in flood risk areas and associated increases in biodiversity and tourism may occur. An increase in non-native species and water shortages due to reduced availability in summer months were also highlighted as particular challenges.

At the landscape-scale, stakeholders were keen to highlight drivers identified by the Broads Authority Landscape Character Assessment, undertaken in 2006 to distinguish the unique range of landscape topologies found within the area (see Broads Authority, 2007b), in collaboration with members from the authority, English Nature (now Natural England), the Norfolk Wildlife Trust and Norfolk County Council. Drivers identified via the Landscape Character Assessment exercise suggested that climate change impacts, such as loss of land due to inundation and saltwater inundation, were likely to place pressures upon relict estuaries (e.g. Breydon – located approximately 25 km east of Norwich) whilst pressures from increasing recreation and tourism were likely to be felt by areas of coastal fringe, such as Somerton (located approximately 20 km north-east of Norwich). A variety of other pressures were also highlighted in discussions and by the report including the development of renewable energy sector, farm payments to enhance conservation management, silting and dredging and the reversion of arable land for conservation. In total, some 100 drivers of change were identified during the exercise and through review of associated documentation (see Broads Authority, 2007a; Broads Authority, 2007b).

Finally, the levels of stakeholder to be targeted by downscaled scenario outputs were identified. It was suggested that as many organisations began working towards landscape-scale initiatives, such as Norfolk Wildlife Trust Living Landscapes (see Norfolk Wildlife Trust, 2011), habitat assessment criteria or biodiversity opportunity mapping, individuals increasingly required mapped scenarios at the landscape-scale. This was increasingly likely to be the case where major conservation organisations developed land management strategies that included plans to target their own land and that of other conservation bodies for land cover change (e.g. Living Landscapes – Norfolk Wildlife Trust, 2011).

Downscaled scenarios in this sense might be utilised to determine where land cover change can be targeted for highest conservation gain. It was suggested that scenarios might depict change over varying timescales in order that both socio-economic and climatic changes were accounted for. Consequently, discussions suggested that downscaled scenarios would be useful to Conservation Officers, Reserve Managers, Landscape Architects, Environmental Planners and Strategy and Policy Officers by offering fully integrated (i.e. agriculture and nature conservation) and multi-objective (economic, social and environmental) futures.

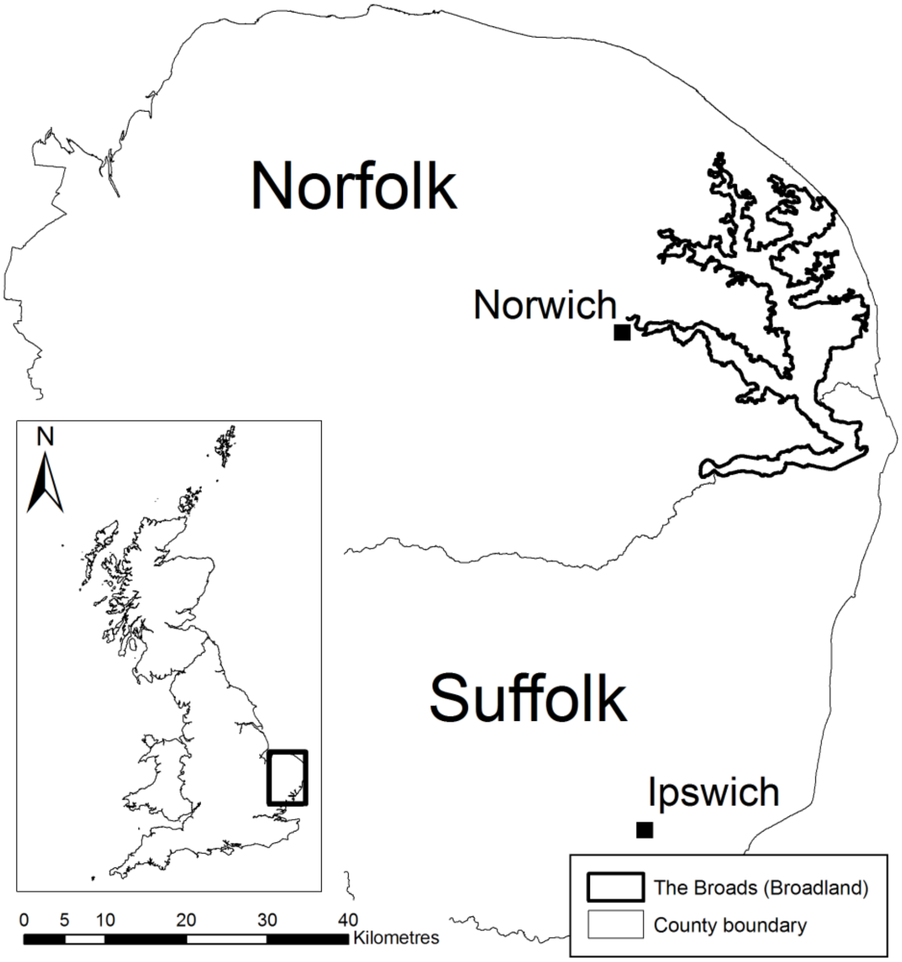

Figure 1.1. Study area overview with UK context map. The Broadland study area. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

1.5. Aims and Objectives

The principal aim of this research is to develop and present a methodology to downscale coarse-resolution scenarios to the local-scale, using a case study of an environmentally sensitive wetland landscape (Broadland).

The work was thus undertaken:

- To identify suitable scenarios and to derive from them a set of localised narratives via a process of downscaling.
- To demonstrate a methodology that can be used to enable the output of coarse spatial resolution land cover data to be downscaled and applied at the local-scale.
- To demonstrate a potential application of downscaled scenarios at the local-scale.
- To investigate the usefulness of downscaled scenarios to local decision-makers.

1.6. Outline of thesis

In Chapter 2, a number of common problems associated with downscaling scenarios are identified. These problems include identifying a range of relevant scenarios from the literature and selecting those most suited to a particular study area, improving the relevance of scenario narratives to local landscapes and mapping of scenario outputs to the local-scale. A potential methodology for dealing with these problems is developed and then discussed using the Broadland case study.

In Chapter 3, the potential for scenarios to be utilised in spatial planning and decision-making is explored and some of the problems of dealing with coarse-scale resolution data, are identified. A GIS-based land cover model is developed and implemented which downscales regional-scale land use data to the local-scale. The output of the methodology is a series of local-scale land cover maps which may be useful for localised studies of habitat fragmentation, connectivity as well as future landscape visualisation. Finally, some benefits and limitations of the approach are also explored.

In Chapter 4, a potential application of the localised land cover maps is demonstrated. Two scenarios, based upon different levels of land management implemented by farmers, are envisaged for two important Broadland breeding wader species (redshank and bittern) and land parcels delineated which may provide suitable habitat arising from a change in land cover. Estimates of population sizes are calculated for individual land parcels and the extent to which the derived land parcels might help to negate recent population declines is discussed with regard to current conservation policy.

In Chapter 5, the usefulness of downscaled scenarios to local decision-makers is investigated. Results from a series of interviews with decision-makers is presented focussing upon four discussion topics; establishing familiarity with scenarios and their current level of use, comparing interpretations of regional-scale and downscaled scenarios, identifying benefits and limitations of the approach and examining the potential role of downscaled scenarios in local decision-making.

Finally, Chapter 6 sets out the conclusions of this work, and discusses avenues for further research.

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Chapter 2

A framework for developing high-resolution scenarios at the landscape scale: the Norfolk Broads

Paul Munday and Andy P. Jones

In review with *Environment and Planning B: Planning and Design*

A framework for developing high-resolution scenarios at the landscape-scale: the Norfolk Broads

Abstract

Improvements in our ability to analyse, forecast, and model future changes in policy and the environment has occurred over the past 20 years. However, there still remain large uncertainties. Scenarios and land use/cover data are often used as tools for investigating the possible future reaction of landscapes to climatic or socio-economic perturbation. Yet, a number of factors may limit scenario application within local landscapes, in particular inapplicable scenario drivers, inappropriate scale (both spatial and temporal) and incompatibility of available data. Landscape characterisation has become a useful tool for highlighting localised future drivers of change but readily available datasets often lack the ability to translate changes described to known land covers or specific areas. Consequently, one must often select and localise existing coarser-resolution scenarios. In this work, scenario types are described, and the range of available scenarios, land cover and landscape characterisation data are highlighted which might be selected for localisation. The role of drivers in influencing scenario outcomes is considered and the potential benefits of incorporating landscape characterisation information in the downscaling process are described using a case study of the Norfolk Broads (Broadland), UK, an internationally important area of wetland.

Keywords: socio-economic scenarios, climate change, downscaling, landscape characterisation

1. Introduction

Our ability to analyse, forecast, and model future changes in both social and physical environments has improved dramatically over recent decades. However, there still remain large uncertainties in predicting the nature and magnitude of changes that may occur (IPCC, 2000; 2001). Consequently we are required to make decisions in the present which are likely to have long-term impacts, whilst we hold little knowledge of the future (Shearer, 2005). This can make it hard to have confidence that the policies being developed now will have their intended consequences.

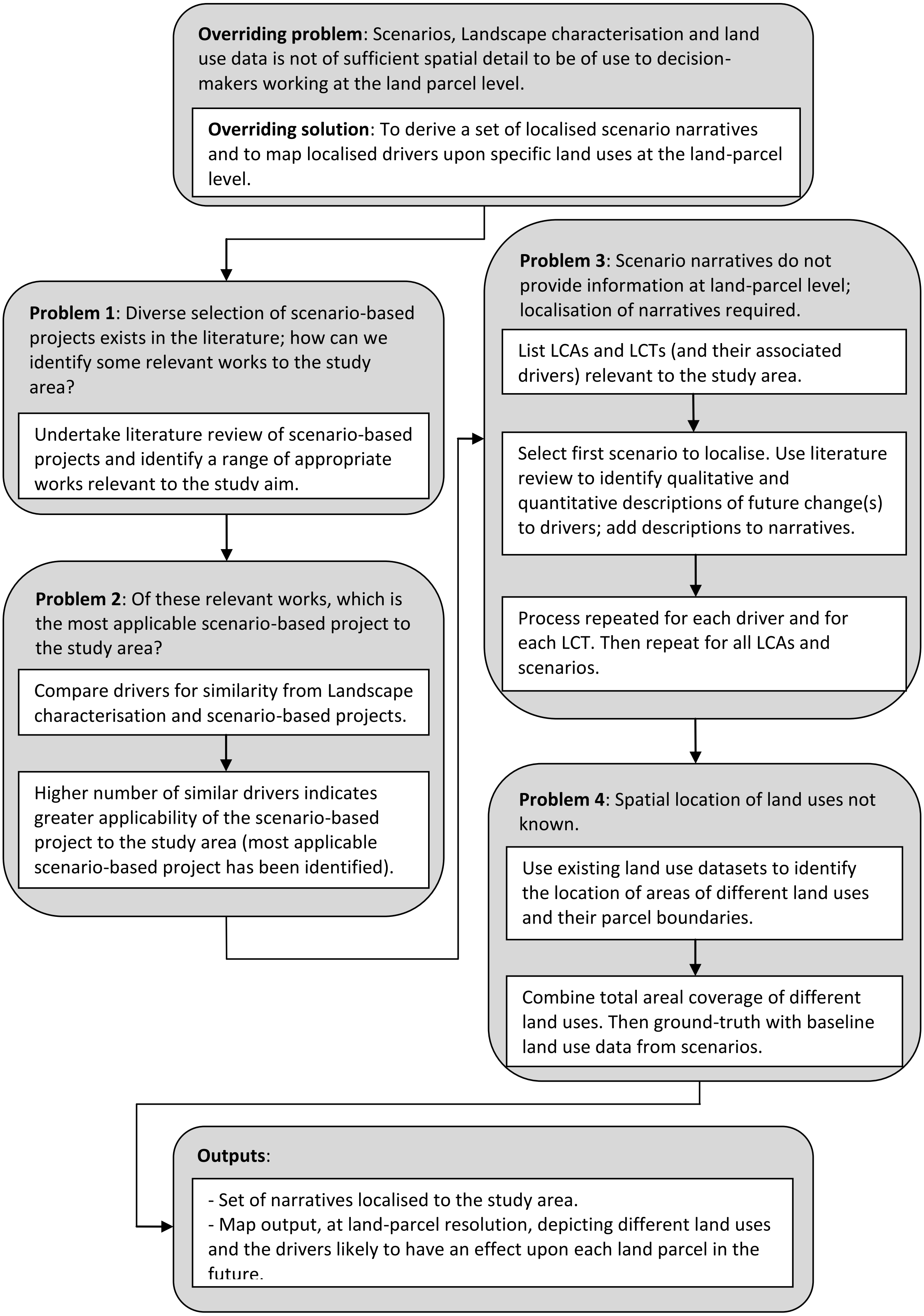
An approach to help manage the uncertainties inherent in decision-making is to compare the consequences of several alternative depictions of how the future might unfold (Berkhout et al. 2002). Scenarios are a tool commonly used for this purpose. They are views of what the future might turn out to be, described not as a deterministic forecast but as one or more possible outcomes (Porter, 1985). A set of scenarios can thus supply narratives of future change and in doing so they provide decision-makers one method of determining the possible magnitude of uncertainty (IPCC, 2000).

Scenario-based projects are studies that have employed scenarios to assess the likely consequences of change, and they have been used to help environmental decision-makers work with uncertainty for over half a century (Shearer, 2005). Examples include investigating the effects of urban expansion (Downs, 1968), the implications of population growth on natural systems (US Environmental Protection Agency, 1975) and the consequences of regional-scale growth (Steinitz and Rogers, 1970). Given the increasing natural and human induced pressures on land cover, an area in which the further development and application of scenarios is particularly valuable is in the evaluation of landscape change.

Landscapes are mosaics over which local ecosystems reoccur, and represent canvasses which document changes in social, economic and environmental systems (Forman, 1995; Abdullah and Nakagoshi, 2008). Landscape characterisation is increasingly being utilised as a tool to quantify the spatial distribution of different landscape types found in regions (Catchpole, 2006). It involves assessments of each aspect of a given landscape: geology, hydrology, soils, ecology, settlement patterns, cultural history, scenic characteristics, land cover, and it typically includes distinct descriptive and evaluative components. It is thus a form of landscape archaeology for understanding and representing landscapes with particular reference to their historical development (McNab and Lambrick, 1999), and it provides a typological classification of landscapes present in an area. This can be useful for examining the possible future evolution of the landscape if the drivers of change acting upon the different typologies can be identified. Drivers are fundamental forces which are likely to modify events in the future. They typically include population change, economic and social development, and agriculture and land use policy change (Schwartz, 1991). Combining scenarios with the outputs of landscape characterisation exercises is thus inherently attractive as it provides a flexible framework against which the future evolution of landscapes can be evaluated. However, identifying scenarios and applying them to drivers within local landscapes is not without challenges (Westhoak et al. 2006; Dockerty et al. 2005).

The UK has three widely adopted sets of scenarios which represent environmental change at a range of spatial and temporal scales; IPCC SRES (IPCC, 2000), UKCIP (Hulme and Jenkins, 1998; Hulme et al. 2002) and RegIS (Regional Climate Impact Studies in East Anglia and North West England – Holman and Loveland, 2002). Other scenarios also exist, including SURPLUS (Office of Science and Technology, 1999); ATEAM (Schrőter, 2004); Regis2 (Holman et al, 2008); PRELUDE (Hoogeveen and Ribeiro, 2005; Hoogeveen et al. 2005) and State of the Countryside 2020 (hereafter SC2020 – The Countryside Agency, 2003). The availability of these pre-existing scenarios can speed up decision-making processes, as new scenarios do not need to be developed from the ground upwards. However, difficult decisions may have to be made regarding which of the scenarios are most appropriate for understanding future change in any given landscape. A further problem is that scenario narratives seldom contain the locality specific information which is needed by decision-makers typically working at a highly localised scale, such as that of individual land parcels. For example, RegIS provides predictions of future land use changes for five kilometre squares but does not specify the location of individual land uses within each square. This is a problem because understanding how the spatial distribution of land uses may evolve at a fine spatial resolution is important for a range of purposes including the study of future habitat fragmentation and connectivity or how the visual amenity of a landscape may evolve (e.g. Dockerty et al. 2005, 2006; Appleton et al. 2002).

A potential solution to the problems outlined above is to develop a means of identifying appropriate national scenarios for any given landscape, and then to derive from them a set of localised versions via a process of downscaling. The downscaled scenarios can then be used to map localised drivers of change upon specific land covers at a fine spatial resolution. The research presented here provides a four stage methodology for implementing this (Figure 2.1), which (i) identifies a range of relevant scenarios; (ii) identifies the most suitable set of scenarios for a local landscape; (iii) improves the relevance of scenario narratives to the local context and; (iv) spatialises the outputs to the land parcel level. The methodology is described before being illustrated using a case study of the Norfolk Broads (Broadland), an internationally important wetland area in the UK.



Overriding problem: Scenarios, Landscape characterisation and land use data is not of sufficient spatial detail to be of use to decision-makers working at the land parcel level.

Overriding solution: To derive a set of localised scenario narratives and to map localised drivers upon specific land uses at the land-parcel level.

Problem 1: Diverse selection of scenario-based projects exists in the literature; how can we identify some relevant works to the study area?

Undertake literature review of scenario-based projects and identify a range of appropriate works relevant to the study aim.

Problem 2: Of these relevant works, which is the most applicable scenario-based project to the study area?

Compare drivers for similarity from Landscape characterisation and scenario-based projects.

Higher number of similar drivers indicates greater applicability of the scenario-based project to the study area (most applicable scenario-based project has been identified).

Problem 3: Scenario narratives do not provide information at land-parcel level; localisation of narratives required.

List LCAs and LCTs (and their associated drivers) relevant to the study area.

Select first scenario to localise. Use literature review to identify qualitative and quantitative descriptions of future change(s) to drivers; add descriptions to narratives.

Process repeated for each driver and for each LCT. Then repeat for all LCAs and scenarios.

Problem 4: Spatial location of land uses not known.

Use existing land use datasets to identify the location of areas of different land uses and their parcel boundaries.

Combine total areal coverage of different land uses. Then ground-truth with baseline land use data from scenarios.

Outputs:

- Set of narratives localised to the study area.
- Map output, at land-parcel resolution, depicting different land uses and the drivers likely to have an effect upon each land parcel in the future.

Figure 2.1. Methodological framework developed to localise scenarios to land-parcel scale. Note: LCA - Landscape Character Area, LCT - Landscape Character Type (e.g. fen, Carr woodland).

2. Proposed methodology for dealing with scenario localisation problems

The methodology developed and implemented here is presented in terms of the four problems that it addresses; the identification of potentially relevant scenarios, selection of the most suitable scenario for a local landscape, improvement of the relevance of scenario narratives to the local context, and mapping of scenario outputs to the land parcel level.

2.1. Problem 1 – Identifying potentially relevant scenarios

Before suitable scenarios can be identified for downscaling it is important to be familiar with the manner by which they are specified and presented (see Wood et al. 2006). Generally, those focussing on characteristics of the landscape use either socio-economic or climatic drivers (or both), are either qualitative or quantitative and may be either normative or descriptive in nature (IPCC, 2000). Normative scenarios describe an ordered set of possible events irrespective of their desirability or otherwise, whereas descriptive scenarios take into account values and interests, often based on specific targets to be reached (Rotmans et al. 2000).

Socio-economic scenarios (hereafter SESs) are usually normative and explore routes to desired or undesired endpoints. They often take the form of images, diagrams or outlines which are presented as narratives or storylines. It is common practice for SESs to be constructed through a participatory approach, whereby viewpoints are gathered via interviews or workshops (see Shackley and Deanwood, 2003). Descriptive scenarios are evolutionary, exploring paths into the future representing elaborations of possible developments (IPCC, 2000). Both normative and descriptive scenarios can be used as aids in decision-making but in different ways. In normative studies, the scenarios tend to represent broad plans for the future and the decision is that of which to implement. In descriptive studies, the scenarios are presented as alternative conditions which are compared, and preference for a particular one allows future uncertainties to be more easily accounted for (Shearer, 2005).

Climate scenarios are almost always quantitative and are usually computed by formalised computer models which provide numerical information in the form of tables, graphs and maps. It has been argued that, by their nature, these type of quantitative scenarios are too deterministic, implying certain trends and assumptions about the future (LUC, 2006). Further, the models underpinning them often represent narrow viewpoints compared with qualitative scenarios where disparate perspectives can be more easily encompassed (Alcamo et al. 2006). For example, numeric models may be used to represent perturbations in crop yields over time, yet subject to the method of model training it is likely that they will produce results only within known limits (e.g. the historical range or mean). Nevertheless, quantitative approaches can be advantageous in that the assumptions underpinning the scenarios tend to be well-documented in the form of model equations, coefficients and inputs and thus more transparent than the assumptions of qualitative scenarios (Alcamo et al. 2006; Shackley and Deanwood, 2003).

A further consideration at the scenario identification stage is the spatial resolution at which potentially adoptable scenarios operate. Although choosing scenarios with high spatial resolution may seem attractive, utilising those which are more diverse in their storylines may be a useful means of understanding uncertainty and improving plausibility of outputs to stakeholders. Further, the selection of drivers which are appropriate to the study area is often of greater importance than spatial resolution as these scenarios will likely require less re-interpretation from stakeholders/ experts via consultations or workshops. Consequently, it is generally necessary to review available scenario-based projects and identify a range that appears potentially appropriate using knowledge of drivers likely to affect the study area and comparing these with drivers from scenario-based projects. The initial candidates can then be further refined.

2.2. Problem 2 - Selection of the most suitable scenarios for a local landscape

Examples of commonly used drivers of change are given in Table 2.1. Drivers of UK landscape change are multifaceted, reflecting the complexity and diversity of UK landscapes (Land Use Consultants, 2006). These drivers typically comprise agricultural policy and support (e.g. DEFRA Agricultural Futures - Morris et al. 2005), land use and land cover change (e.g. RegIS – Holman and Loveland, 2002; ACCELERATES – Rounsevell et al. 2006) and economic development (e.g. UKCIP – UKCIP, 2001; Foresight – Foresight, 2010). These drivers are a key component of the plausibility, and hence suitability, of scenarios. For example, climate change impact studies would be seriously flawed if they assumed future climates would occur in a society similar to that of today (UKCIP, 2001). Additionally, scenarios for use in a small area would be limited if they failed to take account of local distinctiveness (Dockerty et al. 2006). Nevertheless, adoption of drivers can present a number of problems. In particular, selecting those which focus upon policy and limit consideration of natural change is likely to predetermine the importance of policy in future outcomes. Indeed, two UK-based projects, SC2020 and Rural Futures, focused mainly upon social and economic dimensions of rural communities and policy, and therefore these emerged as important drivers. Likewise, the SURPLUS project placed particular emphasis upon the natural environment, and associated drivers emerged as key.

Sector	Main Drivers	Examples
Governance and planning	-Agricultural trade, policy, support and technology* -Energy policy -Environmental legislation and strategies -Forestry Policy -Housing and wider development policy* -Rural policy* -Transport provision/policy* and other infrastructure	-Common Agricultural Policy (CAP) reforms -Agri-environmental schemes and cross compliance measures -EU environmental legislation e.g. Water Framework Directive -National biodiversity strategies - Major planned housing expansion
Demography	-Migration trends and population characteristics	-Migration of families and those of retirement age from urban to rural areas resulting in a wealthier middle-aged rural population
Societal values and behaviour	-Life style choices -Leisure activities	-Increasing desire for rural living -Public acceptability of car use, energy use and waste generation -Greater affluence leading to more discerning and selective customers
Economic and market trends	-Agricultural economy* -Structure of the farming sector and farmer motivation -Land ownership - Skills base -Consumers and markets	-International demand, with a growing food market in Asia, influencing the nature of future agricultural commodity production -The availability of agricultural services such as abattoirs and vets -The growth (or loss) of food retail outlets serving local markets
Technology	-Agricultural technology -Energy -ICT*	-New breeds and crops, Genetically Modified (GM) crops -Responses to rising energy costs and oil shortages - Intelligent Infrastructure Systems (IIS) minimising the need to travel -Changing technologies in renewable energy production; greater emphasis on individual household energy production rather than centralised production
Environmental change	-Climate change* -Energy sources* -Environmental impacts	-Sea level rise necessitating a clear response to coastal zone management -Climate change affecting future land use (increased length of growing seasons, increased drought), cropping patterns and the distribution of farm types and introduction of new crops.-Climate change affecting the resilience of biodiversity and necessitating the landscape-scale management of sensitive habitats -Increasing demand for energy crops and the use of existing woodland to provide biomass, in response to incentives to reduce CO_2 emissions and rising fuel prices

Table 2.1. Main drivers of future landscape change in England. Source: modified from Land Use Consultants, 2006. Asterisks highlights the main drivers which are most likely to influence the character, quality and function of future landscapes as a function of four key scenario studies listed in Table 2.3 (Rural Futures, State of the Country side 2020, SURPLUS and PRELUDE).

Landscape characterisation provides one tool to help determine the appropriateness of different drivers for a given landscape. It is particularly useful because landscape character types can be assigned to individual land parcels and appropriate drivers thus identified for each (e.g. Cornwall County Council, 1996; Dixon, 2007; Swanwick, 2002). The outputs from landscape characterisation assessments are widely available globally (Table 2.2). Advances in the UK have been driven by the publication of a national-scale framework; in 2001, English Nature (now Natural England) mapped distinct units (termed Natural Areas) with their boundaries being defined by their flora and fauna, natural features, and their land cover and human history (see Natural England, 2010). A comprehensive analysis was subsequently undertaken by the Countryside Agency (Countryside Agency and Scottish Natural Heritage, 2001) to identify 181 landscape character areas (hereafter LCAs). These LCAs were defined as single unique areas that had distinct geographical boundaries of a particular landscape type. The agency also identified landscape character types (hereafter LCTs), for example heathland, fen, which were defined as distinct types of landscape that were relatively homogenous in character. The same LCTs occurred in many different areas of the country, and wherever they were present they shared broadly similar combinations of topography, drainage patterns, vegetation and historical land cover. Local Authorities and other bodies have used this framework to interpret policies and inform localised investigations of the impacts of climate or socio-economic change (Broads Authority, 2007b). Landscape characterisation datasets are also available for 14 European countries (for an overview see Wascher, 2005) under the European Landscape Character Assessment Initiative (ELCAI).

The comparison of drivers identified from a landscape character assessment with those used in pre-existing scenarios provides a means of identifying similarity, and hence scenario appropriateness, for a given area. The comparison can be made quantitatively, whereby the number of similar occurrences between drivers is summed, with a higher number of similar occurrences indicating greater applicability. The scenario with the highest level of congruity of drivers can often be selected as the most appropriate for the local context, although elements of more than one scenario can be used in cases where a single choice would leave obvious gaps.

Project	Locality	Resolution	Source
-Verbreitung und Gefährdung schutzwürdiger Landschaften in Deutschland (Protecting Endangered Landscapes in Germany)	Germany	National (1:200,000)	Gharadjedaghi B, Heimann R, Lenz K, Martin C, Pieper V, Schulz A, Vahabzeadah A, Finck P and Riecken U 2004 Verbreitung und Gefährdung schutzwürdiger Landschaften in Deutschland. *Naturund Landschaft* 79: 71–81
-Atlas de los Paisajes de España (Spanish Landscape Atlas)	Madrid (Spain)	National (1:200,000)	Mata Olmo R and Sanz Herraiz C (Eds.) 2003 *Atlas de los Paisajes de España*. Ministerio de Medio Ambiente de España, Madrid. 683pp
-Landscape characterisation in Portugal	Rio Guardiana (Portugal)	National/Regional (1:100,000)	Pinto-Correia T, Canela d'Abreu A and Oliveira R 2003 *Landscape Units in Portugal and the Development and Application of Landscape Indicators*. In: Dramstad, W. and Sogge, C. (Eds). *Agricultural impacts on landscapes*. Proceedings from NIJOS/OECD Expert Meeting on Agricultural Landscape Indicators in Oslo, Norway October 7–9, 2002
-Swiss Landscape Concept (Landscape Concept Switzerland)	Switzerland	Regional (1:125,000)	Walder B S and Glamm A 1998 (Eds.) *Swiss Landscape Concept*. Swiss Agency for Environment, Forests and Landscapes, Berne, 64pp
-The Shropshire Historic Landscape Character Assessment	Shropshire (UK)	Regional (1:50,000)	Wigley A 2006 *The Shropshire Historic Landscape Character Assessment, Draft Final Report*. (Shrewsbury: Shropshire County Council)
-Devon Historic Landscape Characterisation	Devon (UK)	Regional/Local (unknown)	Turner S 2005 Devon Historic Landscape Characterisation: methods, classification and preliminary analysis, unpublished report (Exeter: Devon County Council/English Heritage)
-Landscape Classification in Saxony	Saxony (Germany)	Regional/Local (1:50,000)	Bastian O 2000 Landscape classification in Saxony (Germany) – A tool for holistic regional planning. *Landscape and Urban Planning* 50: 145-155
-HLC in England and a Hampshire case study	Hampshire (UK)	Regional/Local (1:25,000)	Fairclough G J, Lambrick G and Hopkins D 2002 Historic Landscape Characterisation in England and a Hampshire Case Study. In: Fairclough G and Rippon S (Eds) *Europe's Cultural Landscape: Archaeologists and the Management of Change*, pp. 69-83 (Brussels and London: Europae Archaeologiae Consilium and English Heritage)
-The Broads Landscape Character Assessment (pilot study)	The Norfolk Broads (UK)	Regional/Local (1:25,000)	Broads Authority 2007b *The Broads Landscape Character Assessment (pilot study)* Obtained under license from the Broads Authority. 100pp

Table 2.2. Examples of landscape characterisation assessments. Compiled from literature review. Note: resolution represents National-scale (1:250,000 or greater), regional (1:50,000 or 1:25,000) and local (1:25,000 or less).

2.3. Problem 3 - Improving the relevance of narratives to the local context

Narratives from global- or national-scale scenario-based projects seldom completely describe futures that are relevant at the local-scale. In particular, at the land parcel scale, drivers such as competing demands for land or the effects of agricultural policy reform tend not to be well encompassed within current scenarios due to the uncertainty of how they will operate at a very local level. Therefore, downscaling global- or national-scale trends, for example by interpreting the possible impacts of agricultural policy reforms upon local farmers (see Dolman et al. 2001), requires some detail to be added to narratives which will be specific to the local area.

One way of solving this problem can involve listing each LCA and any associated LCTs along with their corresponding drivers. A review of local literature or discussions with local stakeholders can then be used to identify necessary changes to descriptions of scenario drivers in order to make them specific to the local context, and these additional descriptions are added to the scenario narratives, with the process being repeated for each driver and for each LCT, and then for each LCA. If adequately undertaken, this provides a way in which scenario narratives can be downscaled to the local area.

2.4. Problem 4 - Mapping scenario outputs to the land parcel level

Whilst pre-existing scenario narratives allow estimates of future land cover changes to be identified, the majority do not provide any indication of their geographical distributions. An exception in the UK is RegIS, which provides contemporary and predicted land uses for five kilometre square grid cells. Yet even this is too crude to be of particular use if scenarios are being applied to local landscapes, where an understanding of likely changes at the land parcel level is commonly required. Therefore there is a need to downscale these broad narratives to a finer spatial scale. Fortunately, national-scale land use and land cover datasets e.g. Land Cover Map 2000 (hereafter LCM2000) – Fuller et al. 2002 and/or Ordnance Survey Mastermap (hereafter OS Mastermap) – Ordnance Survey (2009) are becoming increasingly available that allow the location of present day land covers and land uses, and their parcel boundaries, to be ascertained. Scenario narratives, and associated drivers of change, may then be mapped onto these parcels. This process is particularly facilitated in localities where a landscape characterisation has been undertaken as the output of the exercise will provide mapped information on landscape types and their associated pressures that is specific to the local context.

We now move on to illustrate how these four stages can be implemented using a case study of the Norfolk Broads (Broadland) wetland, UK.

3. A case study of Broadland, UK

Broadland (Figure 2.2) is a unique area of water, grazing marshes, fen and woodland that is home to some of the rarest plants and animals in the UK. It contains 28 Sites of Special Scientific Interest (SSSIs), amounting to 7,000 ha in total, which benefit from protection either as Special Protection Areas (SPAs) or Special Areas of Conservation (SACs) under European Law. It is also a Ramsar site, reflecting its status as an internationally important wetland habitat. There is good scientific understanding of the ecology of Broadland (Ditlhogo et al. 1992; Cowie et al. 1992). However, pressures for change (e.g. from tourism and recreation, declining markets for traditional products and climate change) mean that the landscape faces numerous pressures.

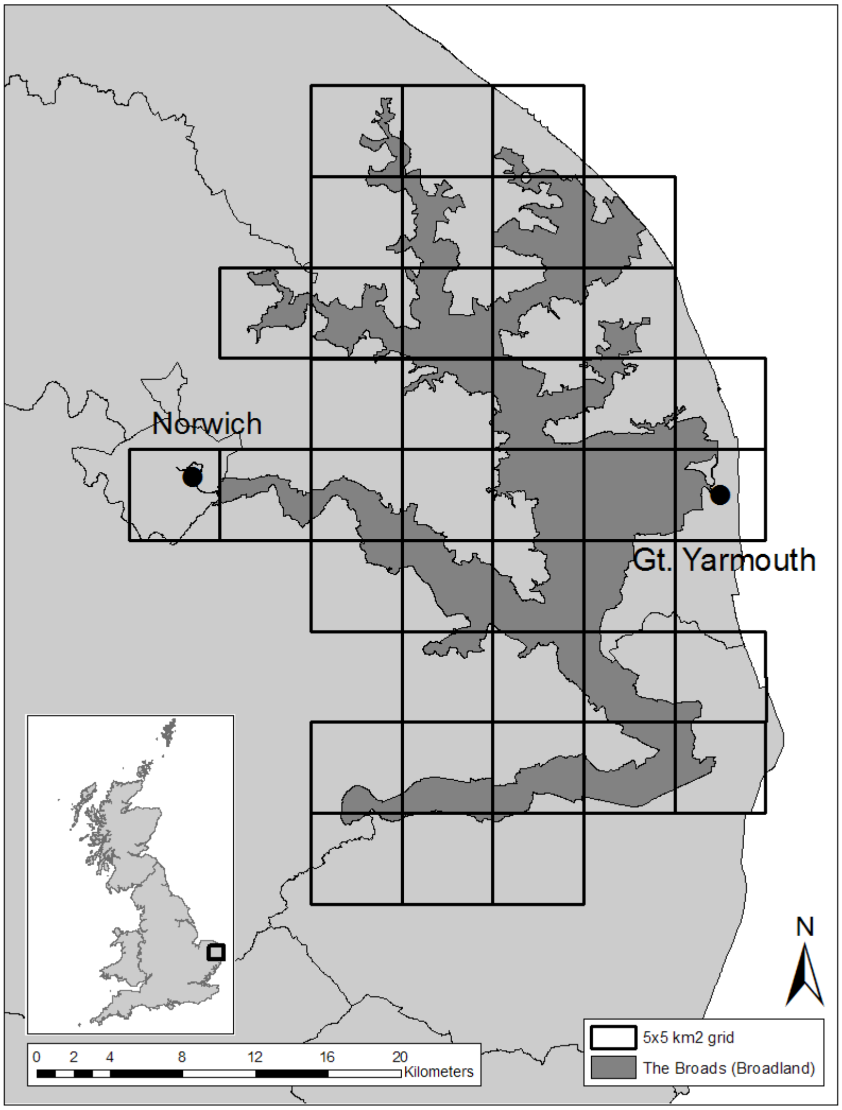


Figure 2.2. The Broadland study area. The Broadland study area and 40 five kilometre square grid cells for which land use data was available. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

As a response to increasing pressures, the Broads Authority (special statutory authority managing the Broads) has instigated a visioning exercise which stipulates the likely future state of Broadland (Broads Authority, 2007a). As part of the project, the impacts of future climate and socio-economic change upon Broadland are being investigated over a 100 year time-scale (see Broads Authority, 2007a, p.21-26). Although existing socio-economic and climate change scenarios may be directly applied to Broadland these tend to ignore, overlook or misinterpret important issues and local drivers, for example the particular significance of agriculture within the area. Consequently, a set of localised scenarios and landscape data is required to facilitate the management of Broadland over the next century.

3.1. Downscaling scenarios to Broadland

A review of existing scenarios was undertaken, and those relevant to the study aim were identified through literature review, an evaluation of their suitability and applicability to different UK habitats, and their level of adoption in other scenario-based studies. Table 2.3 details the published studies which provide outputs that were deemed to be potentially suitable for understanding pressure for change in Broadland.

In 2007 the Broads Authority conducted a pilot landscape characterisation study to help classify and explore the different landscape types and the pressures upon them. Broadland was divided into 31 LCAs, each containing up to 13 LCTs. Figure 2.3 depicts an example of the landscape characterisation dataset produced using the ArcGIS Geographic Information System (ESRI, 2008). The Broads Authority, in collaboration with other conservation bodies (including Natural England and the Norfolk Wildlife Trust) also identified drivers which may have an impact upon each LCT in the future. In total, approximately 100 drivers of change were identified by the organisations across the 13 LCTs.

Scenario-based Projects	Key Drivers	Output	Type	Time-scale(s)	Source
IPCC SRES *IPCC SRES present four possible climate futures based upon GHG emissions*	-Population change -Economic and social development - Energy and technology -Agriculture and land use	-Global climatic variables e.g. CO_2, SO_2,CH_4 -Global socio-economic variables e.g. population, income, energy prices	-QUAN. -QUAL. -DESC.	Up to 2100	-Intergovernmental Panel on Climate Change (IPCC). 2000. *Special Report on Emissions Scenarios (SRES). Working Group III*, IPCC. Cambridge University Press: Cambridge. 595pp. Available at: <http://www.grida.no/climate/ipcc/emission/> [Accessed 10th May, 2005]
UKCIP *Four SESs based upon IPCC SRES and four climate change scenarios applicable within the UK*	As per IPCC but with emphasis placed upon: -Values and policy -Economic development -Settlement and planning	-National-scale climatic variables e.g. temp. humidity, precipitation -National-scale socio-economic variables e.g. GDP, population, land use, subsidies, yield, water demand, biodiversity	-SESs: QUAL. DESC. -CC: QUAN.	SESs: 2020s and 2050s CC: 2100	-Hulme M and Jenkins G J 1998 *Climate Change Scenarios for the United Kingdom: Scientific Report*. UK Climate Impacts Programme Technical Report No. 1, Climatic Research Unit, Norwich, 80pp -Hulme M, Jenkins G J, Lu X, Turnpenny J R, Mitchell T D, Jones R G, et al. 2002 *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp
RegIS *Four equally-plausible future scenarios for socio-economic change explicitly linked to four climate change scenarios for the North West and East Anglia (UK)*	-Derived from UKCIP and inherently the IPCC scenarios	-Regional-scale climatic variables e.g. temp., CO_2, precipitation -Regional-scale socio-economic variables e.g. crop prices, yield, chemical usage, population, land use, set-aside	-SESs: QUAL. QUAN. DESC. -CC: QUAN.	2050s	-Holman I and Loveland P (Eds.) 2002 *Regional Climate Impact Studies in East Anglia and North West England: Technical Report*. Final report to MAFF, DETR and UKWIR. Soil Survey and Land Research Centre, Silsoe. 360pp
RELU *Scenario-based methodology used to explore alternative paths for rural development to 2020 with a view to highlight areas for social science research*	-CAP and agricultural reform -Regulation and governance -Transport -Climate change -Urbanisation and planning -Housing and rural demographies -Consumer demand -Energy and IT	-Nationally applicable socio-economic narratives containing detailed descriptions of key rural drivers projected to 2020 -Intended to develop priority topics for future research	-QUAL. -NORM.	Up to 2020	-Rural Economics and Land Use (RELU) 2004 *Rural Economics and Land Use Scenarios Project*. Prepared by The Institute for Alternative Futures and The Institute for Innovation Research for the Economic and Social Research Council (ESRC). 166pp
Rural Futures *Part of the Horizons Scanning*	-Governance and planning -Demography -Societal values and	-Intended to aid socio-economic policy development for rural areas and identify areas where	-QUAL. -NORM.	2024 and 2054	-Future Foundation 2005 *Rural Futures Project: Scenario Creation and Backcasting: Summary Report and Recommendations*. Prepared for DEFRA, London

Project. Focused upon social and economic aspects of the future of rural communities	behaviour -Economic development -Technology -Environmental change	incentives may be introduced to achieve the desired outcome. Back-casting approach is used -Socio-economic narratives			
State of the Countryside 2020 *Possible futures for rural areas in 2020 and described consequences of multiple drivers of change*	-Governance and planning -Demography -Societal values and behaviour -Economic development -Technology	-Intended to aid rural socio-economic policy deliberation with a focus upon sustainability -Qualitative narratives which are categorically sub-divided	-QUAL. -NORM.	Up to 2020	-Countryside Agency 2003 *The State of the Countryside 2020*. Final Report produced by The Countryside Agency. Available at < http://www.ruralcommunities.gov.uk/files/CA138-StateOfTheCountryside 2020.pdf> [Accessed 17th June, 2007]
SURPLUS *Aimed to improve the ability of DEFRA and others to carry out policy appraisal based on assessment of future changes in land use, recreation, amenity and rural economic activity, and the impact of such changes on the rural environments and rural communities*	-Governance and planning -Demography -Societal values and behaviour -Economic development -Technology -Environmental change	-Intended to aid socio-economic policy appraisal upon rural communities and environments -Socio-economic narratives	-QUAN. -QUAL. -DESC.	2010 to 2025	- Office of Science and Technology 1999 *Environmental Futures. Report for the UK's National Technology Foresight Programme*. Department of Trade and Industry. DTI/Pub 4015/1k/3/99/NP.URN 99/647Ordnance Survey (OS) 2009 *OS Mastermap Topography Layer*. Data available to purchase at http://www.ordnancesurvey.co.uk/oswebsite/products/osmastermap/layers/ topography/index.html [Accessed 27th July, 2009]
PRELUDE *European futures scenario project funded by the European Environments Agency (EEA) present five scenarios of future land use change within Europe*	20 drivers incorporated within five areas: -Environmental concern -Solidarity and equity -Governance and intervention -Agricultural optimisation -Technology and innovation	-Intended to aid deliberation of climate and European development policy but with reference to agriculture, rural development, spatial planning and climate change -Socio-economic narratives with projected variables e.g. population, migration, GDP	-QUAL. -QUAN. -DESC.	2005 to 2035	-Hoogeveen Y and Ribeiro T (Eds.) 2005 *Land use scenarios for Europe. Regional case studies Estonia, the Netherlands, Northern Italy*. Background Report for the European Environment Agency (EEA). 34pp -Hoogeveen Y, Volkery A, Henrichs T and Ribeiro T 2005 *Land use scenarios for Europe – Modelling at the European Scale*. Background Report for the European Environments Agency (EEA). 75pp

Table 2.3. Consulted scenario-based projects. Note: CC=climate change, SES=socio-economic scenario, GHG=greenhouse gas, QUAL.=qualitative, QUAN.=quantitative, DESC.=descriptive, NORM.=normative. *dependent upon start date, report published in 2004.

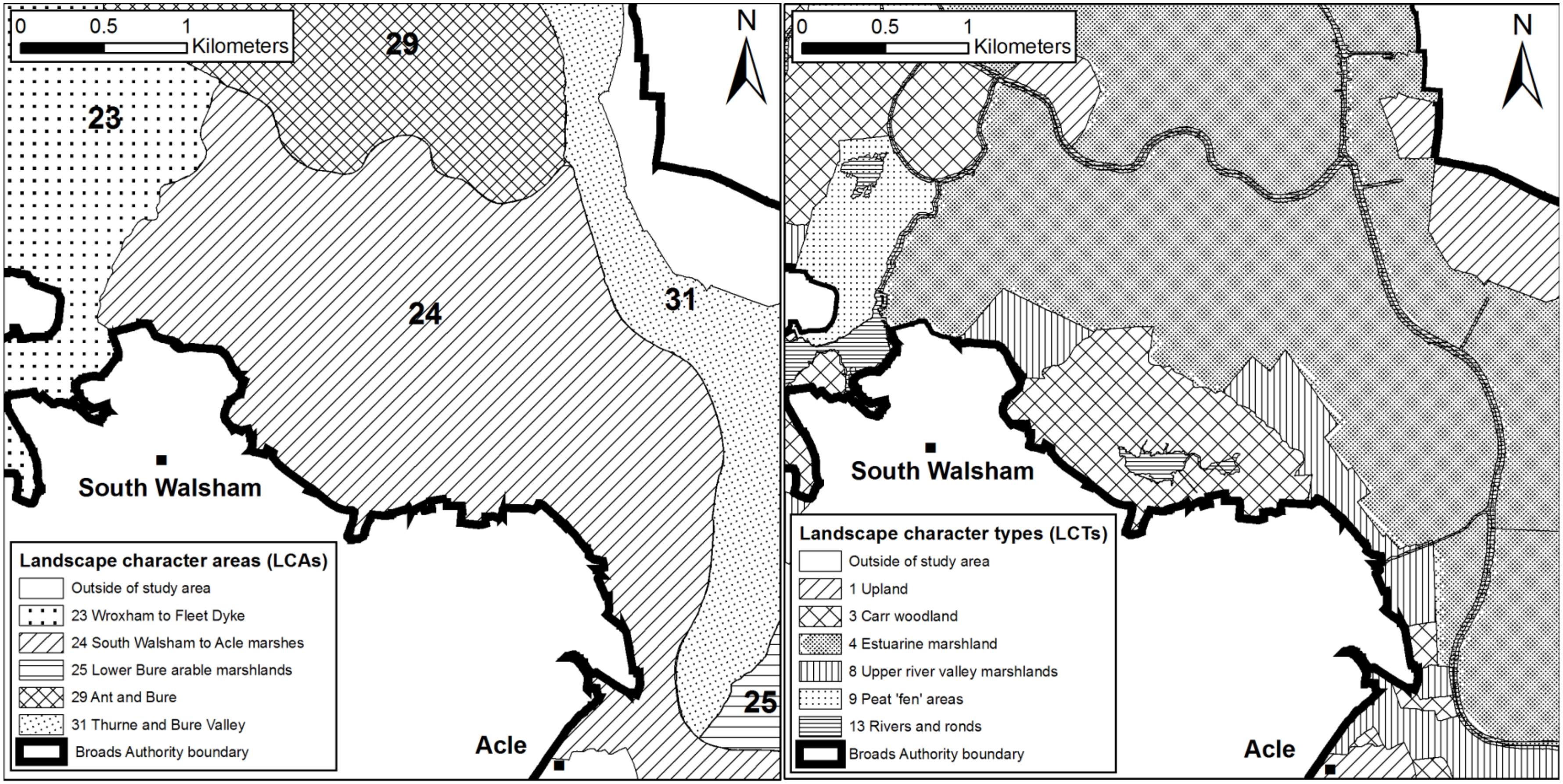


Figure 2.3. Landscape character areas (LCAs) and landscape character types (LCTs). Left: example of several LCAs and location within the Broads Authority boundary. The small towns of Acle and South Walsham are depicted. Right: LCTs within the Broads Authority boundary. Future driving forces following a consultation exercise with several conservation bodies have been identified and can be attributed to individual LCTs. © Crown Copyright. All rights reserved. Ordnance Survey and Broads Authority. 2010.

To identify the scenario-based project that best matched these drivers, they were listed alongside those from the eight potentially suitable scenario-based projects using a matrix. Assessment of the similarity of the pair of drivers forming each cell of the matrix was made by categorising the degree of similarity as either complete, partial or absent. Complete agreement between drivers was determined where both drivers were identical and any described changes were deemed to be wholly representative of one another. Partial agreement was assigned in cases where drivers were broadly similar, yet further refinements were likely to be necessary (i.e. using local knowledge) to become applicable at the land parcel scale. No perceived similarity between drivers resulted in an absent categorisation. The total number of complete, partial or absent occurrences was then totalled in order to determine the most suitable scenario-based project for localisation to Broadland. The UKCIP project scored highest with 12 % complete agreement compared to a range of 4 – 9 % across all other projects. Partial agreement was recorded in 19 % of comparisons compared to a range of 4 – 12 % across all other projects. Agreement was absent for 69 % of drivers (range across all other projects of 78 – 91 %). This process therefore suggested that UKCIP was the most applicable work to localise. It comprises four descriptive scenarios based upon drivers of values and policy, economic development and settlement and planning, to the year 2050. The futures envisaged vary between different levels of government autonomy or independence and increasing consumerism or community values. Detailed narratives are provided for each scenario (see UKCIP, 2001) in the context of six impact domains; agriculture, water, ecosystems, coastal zones, tourism and the built environment.

Next the UKCIP narratives were localised to improve their applicability to the study area. This process is described using the example of a single LCA (Number 24 – South Walsham to Acle Marshes and Fens). In this example, the UKCIP Local Stewardship (hereafter UKCIPLS) scenario is chosen for localisation as its drivers and narratives are particularly representative of the future envisaged by the Broads Authority visioning exercise (Broads Authority, 2007a). Initially a review of literature relevant to this scenario for Broadland was undertaken (in this case, UKCIP, 2001; Shackley and Wood, 2001; Shackley and Deanwood, 2003; Broads Authority, 2007b). Table 2.4 provides examples of the localisation process for a selection of narratives. In total, 80 localised narratives were constructed for LCA24. This process was repeated for each LCA and for all four UKCIP scenarios.

Scenario-based project driver	Original narrative	LCT driver	Localised narrative for LCA#24 (South Walsham to Acle Marshes and fens)
Water: *Water supply*	There is an increasing consciousness that water resources have to be protected. Exchange of water resources between regions in the UK becomes more difficult. High water-using activities either innovate in regions with shortages (like the South East) or relocate to other regions. Major investments are made to reduce water leakage. Few new supply-side investments are needed.	*Lack of fresh water in summer months*	As original narrative but with these additions (see below) Gradual rising of salinity due to reduced fresh water availability (reduced precipitation). Salt-tolerant species increasingly able to survive e.g. salt grass and glasswort. Distinct zoning with elevation where transitions occur, or more frequently, one species gradually giving way to another resulting in broad transitional zones. A reduction in available water may mean the proportion of irrigated crops will be replaced by cereals. However, the focus upon 'home grown' produce may temper this trend. More on-farm reservoirs meaning less water are abstracted from rivers during the dry summer months.
Agriculture: *Agricultural Policy*	The main goal of agricultural policy is to support the broader social desire for local self-sufficiency and what are seen as traditional farming practises. Research and technical support increases the productivity of low-input farming systems. Large-scale farming is not encouraged.	*Changes to farm economy/subsidy system*	As original narrative but with these additions (see below) Protectionist policies introduced to maintain areas used for agricultural purposes. Subsidies for conservation farming in Acle. Farming of energy crops, oilseed rape and coppicing are also increased. Diversification into niche markets (e.g. vineyards, racehorses etc.) and an increase in local speciality produce in order to supply farmers' markets. Subsidised revival of pick-your own (PYO) apple orchards.
Biodiversity: *Nature Conservation Policy*	There are strenuous efforts to preserve wildlife at the local level, both in rural and urban areas.	*Wetland creation and enhancement projects*	As original narrative but with these additions (see below) Areas that were protected in the 2000s are still maintained and subsidised. More protected areas have been introduced, primarily to protect biodiversity, including wetland nature reserves. Increasing population means there are more visitors to these protected areas for recreational use. Therefore, new footpaths and parking areas are created. Reduced 'Right to Roam' due to increased visitation.
Economic Development: *Regional Trends*	Greater emphasis is placed on regional development and the local economy as a way of achieving sustainable social and environmental benefits.	*Future of reed and sedge industry*	As original narrative but with these additions (see below) Sustainable local production of reed and sedge continues and is still encouraged. Demand remains relatively consistent with current norms (in keeping with traditional focus of this scenario). More training of cutters as a mechanism to preserve local heritage.

Table 2.4. Example localisation of a scenario narrative for an area of Broadland using landscape characterisation data. Localisation was undertaken using literature review.

As scenario narratives became modified, the degree by which the landscape characterisation drivers might still be plausible was considered. It was apparent that the majority of drivers remained robust and plausible with just 10 % deemed no-longer suitable. An example of non-suitability is in the case of the UKCIP World Markets scenario (where pressures upon the economy and environment are most prevalent); it is unlikely that areas of wet lowland grassland and marshlands, which are typically high in biodiversity, would remain given the increasing pressures from sea level rise and flood frequency, agricultural intensification and weakened nature conservation policy. Consequently, the drivers identified via landscape characterisation appeared to be mostly representative of a range of different futures. This is reassuring, as it helps address issues of uncertainty in scenario narrative projections.

The final stage involved the translation of localised scenario narratives into the pressures for changes in land cover at the land parcel level. Whilst the UKCIP project was deemed to be the most applicable scenario-based project to Broadland, it is not spatial in nature. Fortunately, RegIS (Holman and Loveland, 2002) represents a spatialised version of UKCIP, albeit at a somewhat crude spatial resolution. RegIS provides information on areas of four land cover types, arable, permanent grassland and urban and woodland, within five kilometre square grid cells across East Anglia. In total 40 grid cells overlay the study area (see Figure 2.2). RegIS gives estimates of recent (1995) and future (2050) land cover areas (in ha) within each grid, although the precise location of each land cover is not defined.

Two socio-economic scenarios, Regional Enterprise and Global Sustainability (hereafter RE and GS respectively) are provided in RegIS which are related to the UKCIP National Enterprise and Global Sustainability scenarios, respectively. Both characterise contrasting future worlds in which the future is driven by a number of key drivers (e.g. agricultural policy, climate change and economic development). It is noteworthy that although the UKCIP National Enterprise and RegIS Regional Enterprise scenarios both occupy the same conceptual space, and therefore are similar in terms of their level of governance and values that they prescribe (see UKCIP, 2001), the RegIS Regional Enterprise scenario is different in the sense that it follows a more economically vibrant future than that of the more stagnant UKCIP National Enterprise scenario (see Holman and Loveland, 2002). In addition to the two socio-economic scenarios, two climate scenarios (UKCIP High and Low – see Hulme, 1998) were also modelled by RegIS at two time-points; 1995 (the baseline) and 2050.

The first stage of spatialising the modified scenario narratives to the land parcel level involved mapping the likely locations of the four land cover types from the RegIS baseline. This allowed the translation of scenario narratives to individual parcels within the study area. To assist with this, an existing 25m resolution land cover dataset was utilised (LCM2000). Initially, the degree of agreement between the RegIS and LCM2000 datasets was explored. The LCM2000 dataset was reclassified to make it compatible with RegIS, identifying agricultural, permanent grassland, and urban and woodland categories. Visual ground-truthing of 1000 points was undertaken using 25 cm^2 resolution aerial photography from 2004, and 88 % correspondence was noted. At the scale of the 5 kilometre grid cells, correlations of the percentage of each land cover between RegIS baseline and LCM2000 were found to be high; for arable (r=0.716, p<0.01), permanent grassland (r=0.651, p<0.01), urban (r =0.978, p<0.01) and woodland (r=0.925, p<0.01).

As LCM2000 is based on remotely sensed satellite imagery, and hence it is difficult to identify land parcel boundaries from it, OS MasterMap® 1:1250 was utilised to provide information on these boundaries across the study area. The LCM2000 layer was converted from raster to vector format, and OS Mastermap parcels were classified on the basis of the predominant LCM2000 categories falling within each, in order to provide a present-day baseline map.

When comparing the land cover parcels that had been derived using the OS Mastermap and LCM2000 datasets with the baseline RegIS data it was notable that permanent grassland and urban land covers were replicated with great accuracy The area of permanent grassland was overestimated by a mean value over the study area of just +0.19 % compared with the baseline RegIS data, and urban areas were underestimated by just -0.88 %. Woodland was less well replicated and was overestimated by a mean value of +4.97 %. This is possibly because LCM2000 was not able to depict small clumps of trees due to its spatial resolution. Underestimation of the amount of land in agriculture (-4.28 % compared with the baseline RegIS data) may partly be the result of policy on set-aside which has varied the amount of fallow land annually since 1995 (DEFRA, 2008). Nevertheless, for the purposes of this work, the differences in land cover totals described were deemed to be acceptable.

The completion of this stage provided a downscaled set of set of land cover data and associated narratives for individual land parcels across Broadland. Figure 2.4 provides an example of the type of mapped output generated for a 5 kilometre square grid. The map illustrates how the methodology allows the user to interpret the likely future drivers of change upon individual land parcels and their associated land covers at a high spatial resolution. For example, the arable areas within LCA24 are likely to be threatened by recreational pressures whilst those within LCA25 are likely to be threatened by a lack of fresh water. Further, changing water levels are likely to threaten woodland within LCA24 whilst pressures from aggregate extraction are predicted to impact upon the woodland areas within LCA25.

Figure 2.4. Derived land cover parcels and LCT drivers mapped to land parcels within a five kilometre square grid. The map represents the 1995 RegIS base map with the four GIS derived layers depicted. The town of Acle is located to the south-west of the map. Note: areas overlain with driver threats which are not identified (i.e. white zones between arable fields) are influenced by the driver in question, however, only four land covers are considered for the purposes of this analysis. © Crown Copyright. All rights reserved. Ordnance Survey and Broads Authority. 2010.

5. Discussion

This work identified four problems that are associated with applying coarser-scale scenarios and land cover data within local landscapes, and has presented a methodology to help overcome them. Key contributions include the reduced need for input and resources in the localisation process due to the possibility of adapting national-scale scenario narratives, rather than developing entirely new ones. This type of approach might hence appeal to local decision-makers working with limited budgets or under particular time constraints. The land parcel scale outputs also provide a useful input into, for example, cartographic visualisations of pressures of change (e.g. Dockerty et al. 2006), local visual amenity planning (e.g. Appleton et al.2002; Ghadirian and Bishop, 2008), or studies of landscape fragmentation (e.g. Southern et al. 2006). Finally, the methodology presented is transferable and may be equally applied in different localities.

Despite the advantages, the methodology does suffer from a number of limitations as presented. Downscaling national-scale trends can be problematic where the assumptions underpinning them are not directly applicable within the study area or are difficult to interpret. This is particularly a problem where scenario literature (especially narratives) is vague or non-descript. This problem is amplified in areas that are unique in their nature and where national-scale scenarios may be less applicable. As the methodology presented is reliant on the availability of descriptive literature regarding potential scenarios, there is the potential for bias where those scenarios that are best documented are more likely to match better with drivers in the case study area. Whilst this may be acceptable it does mean that scenarios which may be less well documented, but could be interesting in that they describe more extreme futures, could be overlooked.

The methodology as presented is also limited in its ability to take into account additional threats at the land parcel scale, such as local planning policy (e.g. housing development boundaries or changes to access which might not result in alterations to landscape character) that may not be considered in the original scenarios. In reality, the timing and spatial distribution of such changes is notoriously difficult to predict as they usually occur in sudden jumps punctuated with periods of marginal change in between. Although drivers identified via landscape characterisation assessments are often spatially detailed they can sometimes be limited by their inability to incorporate such unpredictable and localised trends.

A final criticism might concern the simplification of land covers from land use datasets, such as LCM2000 and OS Mastermap. Whilst remotely sensed satellite imagery (e.g. LCM2000) allows more accurate delineation of land cover categories at regional-scales, individuals working at the land parcel level may find the resolution too crude. Further, the methodology presented here has used two datasets to derive land cover categories which were developed using different methodologies, including satellite remote sensing (e.g., LCM2000) and field surveys (e.g., OS Mastermap); these disparities may account for some of the differences implied by the results.

Despite these limitations, the outputs presented here have a number of potential benefits for local decision-makers and land managers. For example, the methodology and outputs presented might be useful in guiding the development planning legislation (e.g. Local Development Frameworks – see Broadland District Council, 2006) and to local planners undertaking zoning of land parcels as the outputs provide insight into the potential pressures that each parcel might experience in the future.

6. Conclusions

A number of problems limit the application of coarser-scale scenario narratives and land use data to local landscapes. The increasing availability of spatially detailed and locally relevant data such as that from landscape characterisation assessments provides decision-makers with the potential to map potential future drivers of change to individual land parcels. Methodologies, such as that presented, to overcome these problems may improve the relevance of coarser-scale scenarios and land cover data to decision-makers and land managers whilst allowing threats to be mapped to individual land parcels. This may provide input into future landscape planning and management policy.

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Chapter 3

Utilising scenarios to facilitate multi-objective land use modelling for Broadland, UK, to 2100

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Utilising scenarios to facilitate multi-objective land use modelling for Broadland, UK, to 2100

Abstract

Landscapes that we see today will change in the future. Scenarios are used as a method for dealing with uncertainties in change and to provide plausible descriptions of our future world. A number of projects have utilised scenarios and a modelling-based approach to quantitatively investigate land use/land cover change at the national/regional-scale using a GIS. However, the coarse-scale of such data can render outputs inapplicable within local, often environmentally sensitive, landscapes. Improving data resolution allows us to investigate alternative potential futures at greater detail thereby providing vital input into policy and future decision-making. It may also facilitate localised studies of habitat fragmentation connectivity and visualisation. This paper utilises scenarios and regional-scale land cover change data to facilitate a GIS-based model of land cover change within a sensitive wetland environment. Land cover change data from the RegIS project is localised to the study area in Broadland, UK. Areal totals, from the land cover change data, are replicated within 0.01 % of areal totals prescribed, enabling very spatially detailed land cover maps to be developed. This work represents a locally explicit realisation of coarser regional-scale land cover change data using an integrated GIS-Multi-Criteria Decision Analysis (GIS-MCDA) methodology.

Keywords: multi-objective, multi-criteria, GIS, land cover, scenarios, resolution

1. Introduction

Over many centuries, substantial and continuous land cover change has occurred within the UK, driven by societal, economic and environmental pressures, and the impact of these driving forces is unlikely to lessen in the future (Ratcliffe, 1984). Changes in land cover will influence a variety of different systems including, biotic diversity (e.g. Sala et al. 2000), ecosystem processes and functions (Millennium Ecosystem Assessment, 2005) and the climate system (e.g. Chase et al. 1999; Lambin et al. 2000). It is likely that changes to these systems will place increasing pressures upon people and places, and their ability to adapt to changing environmental conditions (Kasperson et al. 1995).

Nevertheless, decision-makers, experts and stakeholders must still make choices today which may influence how the landscape alters and is used in the future.

Scenarios can be used as a tool to describe a range of different futures. For the purposes of this research, scenarios are defined as views of what the future might turn out to be. In this sense, they are not necessarily actually forecasts but instead represent one or a number of possible outcomes or states (Porter, 1985). Decision-makers have used scenarios for a range of different purposes including undertaking impact assessment analysis (Jefferson, 1983; Schwartz, 1991), policy formulation (Davis, 1999) and sustainable energy use (Häfele et al. 1981; World Energy Council, 1993). Scenarios may employ varied drivers of change which represent principal components that influence the evolution of the world in general (Abildtrup et al. 2006). Scenarios might use drivers which are societal (e.g. the strength of society's social values and political direction), economic (e.g. the rate of economic development) and environmental (e.g. rates of sea level rise) to help provide plausible, qualitative (broadly textual) descriptions of a future world many years ahead (IPCC, 2000).

A variety of different projects exist that provide scenarios which may be adopted for the purpose of investigating the impacts of climatic and socio-economic change on landscapes. These are at a range of spatial scales including: European e.g. IPCC Special Report on Emissions Scenarios (IPCC, 2000); national e.g. UKCIP (Hulme and Jenkins, 1998; Hulme et al. 2002) and regional e.g. RegIS (Regional Climate Impact Studies in East Anglia and North West England – Holman and Loveland, 2002). Additionally, other projects (e.g. PRELUDE – Hoogeveen et al. 2005; ACCELERATES – Abildtrup et al. 2006; REGIS2 – Holman et al. 2008; ATEAM – Schrőter, 2004) exist which provide quantitatively derived datasets (typically output from purpose-built models which consider land cover or agricultural change) which reflect the same, or similar, manifestations of scenario drivers seen in qualitative scenarios but depict changes in the form of spatially mapped data (e.g. land cover change), developed using a Geographic Information System (GIS).

Despite their potential for use in spatial planning and decision-making, the majority of scenarios do not lend themselves well to application within local landscapes due to their relatively poor spatial resolution. For example, the RegIS project provides qualitative scenarios and quantitative land cover data which are intended for application at a five kilometre square grid cell resolution, yet the dataset gives no indication of the precise location of individual land cover types within each grid cell. Providing decision-makers with locally-explicit, and plausible, qualitative scenarios and quantitative data, detailing how local areas might respond to future drivers of change is of paramount importance if we are to understand how local areas might react to climatic and socio-economic change.

Additionally, in order to better understand landscapes and the processes that influence their development, we also need to see how they might look under future scenarios. For example, locally explicit data can facilitate focused studies of habitat fragmentation and connectivity (e.g. Southern et al. 2006; Hill et al. 1999), as well as biodiversity impact assessment and future landscape visualisation for the purposes of determining visual amenity (e.g. Dockerty et al. 2005; 2006; Sheppard and Meitner, 2005).

This research seeks to demonstrate a methodology that can be used to enable the output of coarse resolution scenarios to be downscaled and applied at the local-scale. A case study of the Norfolk Broads (East Anglia), UK, an environmentally sensitive and internationally important wetland habitat, is used to illustrate the production of a GIS-based model of land cover change using regional-scale data. The output from the methodology is a series of localised land cover maps based on plausible scenarios which describe the reaction of the area to national and regional-scale drivers of change from the present day to the year 2100.

Firstly, the role of GIS within scenario-based studies is discussed in this paper and some of the problems of dealing with coarse-scale resolution data are identified. Next, the implementation of the methodology is introduced using the Broadland case study. Finally, the benefits and some limitations of the methodology are reviewed.

1.1. GIS and scenarios

The benefits of employing GIS within scenario-based studies are plentiful. For example, GIS allows decision-makers to depict multiple spatial variables (e.g. changes in climate, habitat or agriculture) that scenarios describe (e.g. Berry et al. 2007). Further, GIS also allows visual depiction of uncertainty and the outputs from sensitivity analyses which are often difficult for individuals to conceptualise (e.g. Appleton et al. 2004). Scenario narratives often contain information about numerous factors which are spatially distributed. For example, the national-scale UKCIP (2001) project contains scenarios which describe future employment trends, economic development and changes in land cover, all of which show marked geographical disparities. Whilst the ability of a GIS to manage spatial data so as to enable decision-makers to link varying sources of information, perform analyses, and project trends or outcomes, is of particular benefit to scenario-based works (Sumathi et al. 2008), GIS can also be utilised to represent scenarios in ways that make them more tangible or 'real' (Wollenberg et al. 2000). Indeed evidence suggests that the presentation of the scenario in the form of a map or virtual-reality visualisation can encourage greater understanding and participation from stakeholders in the decision-making process (Tan-Kim-Yong, 1992). For the purposes of downscaling coarser national- or regional-scale data, these are particularly important qualities, especially if outputs are to be used by individuals with varying qualifications and/or experience of them.

Decision-makers essentially have two choices when they require scenarios to apply within local areas. Firstly, entirely ‘new’ scenarios might be developed through extensive local expert and stakeholder consultation (e.g. Southern et al. 2006). Alternatively, scenarios can be adopted from pre-existing scenario-based projects (e.g. UKCIP, 2001) and localised, through refinement of scenario narratives with local experts and stakeholders. However, an inherent difficulty associated with the first approach is that creating original scenarios is often time-consuming, resource intensive and hence unappealing for local decision-makers working within restricted budgets and with limited expertise in scenario development. Thus, it is often prudent to take the second approach.

One problem associated with scenario-based studies is that of dealing with data at coarse spatial resolution which users subsequently find difficult to interpret within local areas. For example, the PRELUDE project provides mapped land cover data within 10 minute (latitude and longitude) grids for application within EU-25 countries, with additional data output at the 500 m grid scale for just three countries; Estonia, Italy and the Netherlands. Further, the RegIS project provides outputs on the areal coverage of 28 different agricultural crops, set-aside, and urban and woodland extent within five kilometre square grids. However, the location of each land use type within individual grids is not specified. In addition, the RegIS data is restricted to the period of 1995-2050. For those investigating the impacts of climatic and socio-economic change on longer timescales, this can be limiting and hence, to be adopted in localised studies, it is often necessary to develop a baseline which represents the current environmental state of the study area from which changes can be projected.

1.2. Multiple criteria

Quite often, decision-makers may need to consider several different, often conflicting, criteria (e.g. conservation vs. development) in order to reach a particular objective (Carver, 1991). In this context, a GIS is an extremely useful tool in helping assimilate and manage large amounts of data in order to reach an appropriate solution. In some instances, weights are required to be applied to these criteria where the solution to the problem is not Boolean in nature; for example, perhaps in the development of maps of land cover suitability where multiple criteria of differing importance compete for the same parcels of land (e.g. Collins et al. 2001; Hossain et al. 2007). This weighting procedure is typically applied in the GIS and is achieved via stakeholder and expert consultation. However, such consultation exercises are often resource intensive and this procedure might not be suitable for local decision-makers working with limited budgets.

Driven by the demand for GIS software which is able to consider multiple criteria, a substantial increase in the volume of GIS and Multi-Criteria Decision Analysis (hereafter GIS-MCDA) work has taken place over the past *c*. 15 years (Malczewski, 2006). The introduction of MCDA tools in GIS systems such as IDRISI (Eastman et al. 1993b) and TNT-GIS (MicroImages Inc. 2001) has further accelerated this trend. In particular, the availability of a multi-functional decision support suite in IDRISI has been significant in encouraging applied research (e.g. Brookes, 1997; Giupponi et al. 1999; Jiang and Eastman, 2000; Kyem, 2001, 2004). These systems allow users to easily weight multiple criteria and to receive feedback on the potential implications in the form of digital maps reflecting possible changes in land cover.

Despite the increase in the use of GIS-MCDA, there are few methodologies to generate spatially detailed model outputs from coarse scenario input data. Further, our understanding of the benefits from integrating GIS and MCDA is limited by the lack of research on conceptual and operational applications of the use of MCDA in solving real-world problems (Malczewski, 2006; Kyem, 2001). Consequently, the objectives of this paper are threefold: (i) to develop a baseline land cover map of the Broadland study area; (ii) to create a land cover model which is able to replicate RegIS regional-scale land use change data, at a local-scale, for the year 2050, and; (iii) to project land cover trends, seen between the period 1995-2050, to the year 2100.

2. Methodology

2.1. Study Area

The Broadland landscape (Figure 3.1) comprises grazing marshes, fen and woodland, as well as intensive arable lands that support numerous threatened and scarce species of flora and fauna of high conservation concern. It contains protected areas amounting to 7,000 ha in total including Sites of Special Scientific Interest (SSSIs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and is also designated with Ramsar status, reflecting its international importance as a wetland habitat. There is good scientific understanding of the ecology of Broadland (Cowie et al. 1992; George, 1992) and studies detailing its unique and distinctive landscape character (Countryside Commission and English Nature, 1996). However, pressures for change (e.g. from tourism and recreation, declining markets for traditional products, and climate change) mean that the landscape that we see today faces conflicting demands.

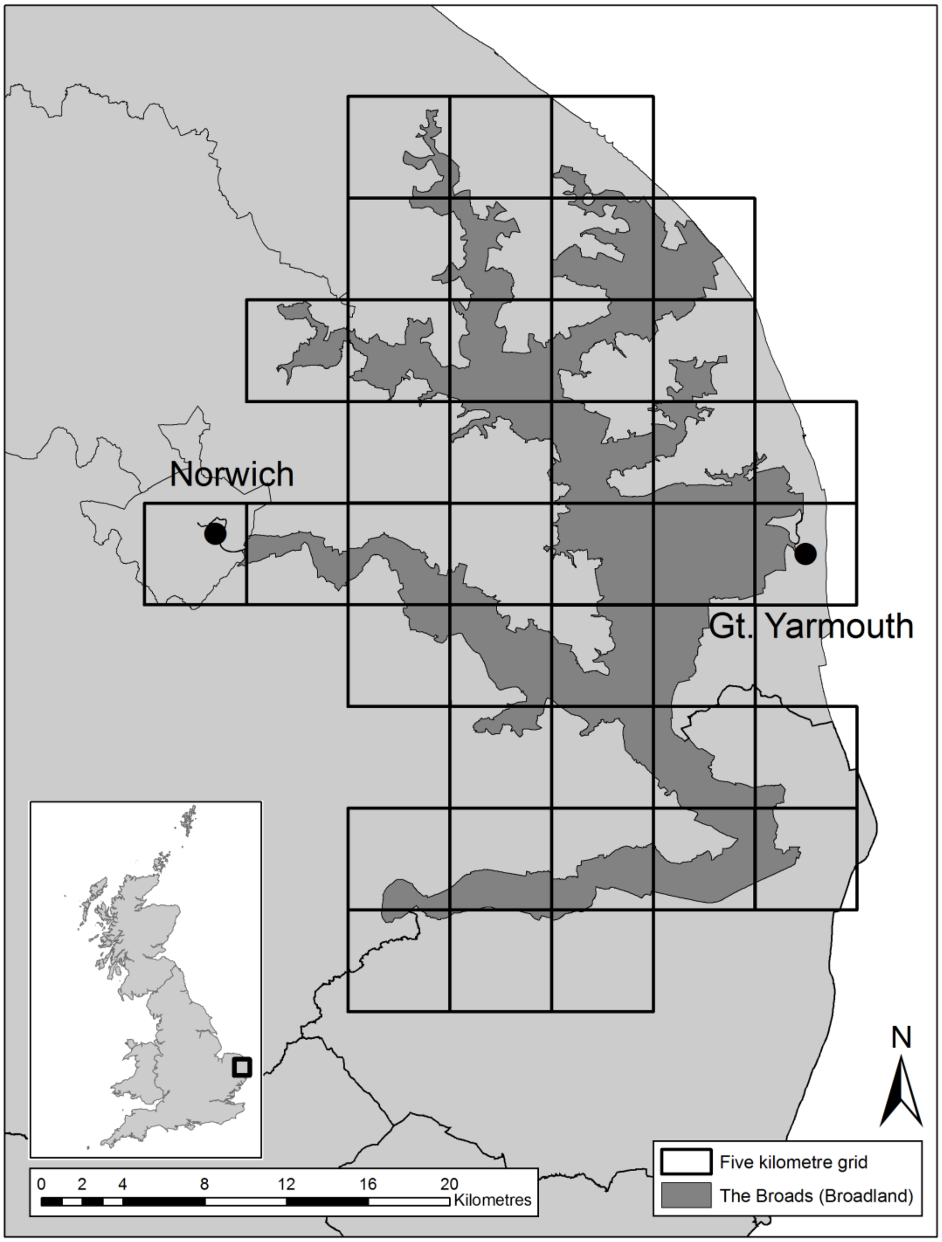

Figure 3.1. The Broadland study area. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

A multitude of social, economic and environmental threats and/or opportunities (e.g. changing agricultural policy, climate change, economic support measures) are likely to influence future land cover trends within Broadland. Owing to its complex management, environmental sensitivity and competition for land cover, the need to identify how these changes may result in modifications to the landscape is pressing. Indeed, the need for a more adaptive management style which reacts to changing future conditions has been highlighted (Folke et al. 2003; Sutherland et al. 2004). As a response to the issues described, the Broads Authority (the Special Statutory Authority managing the

Broads) has instigated a 20-year 'visioning' exercise. This project stipulates the likely future state of Broadland due to environmental (e.g. climate change), societal (e.g. policy – specifically, UK Biodiversity Action Plans and the Habitats and Birds Directives) and economic (e.g. tourism) drivers between 2004 and 2024 (Broads Authority, 2007). As part of this project, the impacts of future climatic and socio-economic change upon Broadland are also being investigated over a 100 year time-scale (see Broads Authority, 2007, p.21-26). Such initiatives are important catalysts for exploring potential future land cover change in the region, but they are limited by the lack of information pertaining to changes that might be witnessed on-the-ground. Hence a set of localised land cover maps may help planning and management of the landscape (e.g. identifying areas where they may be particular pressure for land-use transition), evaluating the feasibility of environmental policy (e.g. the impact of possible changes to agricultural policy), and communicating change to stakeholders (e.g. via computer visualisations).

2.2. Scenarios and land cover change data

A review of available scenarios was undertaken, and the RegIS scenarios were identified and selected for application to the study area, primarily because they represented the highest resolution scenario-based dataset available for Broadland (see Holman and Loveland, 2002; Shackley and Deanwood, 2003; UKCIP, 2001). The RegIS scenarios are derived from UKCIP scenarios which feature extensive documentation and are already widely adopted in a variety of other studies (e.g. Wood et al. 2006; Firth and Hutchins, 2006) making them suitable for application here. Two socio-economic scenarios (Regional Enterprise and Global Sustainability) are provided which are related to the UKCIP National Enterprise and Global Sustainability scenarios respectively; both socio-economic scenarios (SESs) characterise contrasting future worlds in which the future is driven by a number of key drivers (e.g. agricultural policy, climate change and economic development).

The Regional Enterprise (hereafter RE) scenario represents a world in which the economy takes precedence over natural systems. Biodiversity is under threat from habitat fragmentation, increasing pressures from development and weakened environmental controls. In the Global Sustainability (hereafter GS) scenario, natural ecosystems are considerably less vulnerable to change (e.g. due to climate) and greater environmental protection is granted due to stricter social values which discourage development within areas of conservation and strengthened environmental protection policies (e.g. growth in areas afforded protected status). Demand for access to the countryside increases whilst pollution levels fall. In this scenario, economic growth is afforded less importance than environmental sustainability (for comprehensive storylines and narratives see Shackley and Deanwood, 2003; UKCIP, 2001). These two SESs represent two rather broad, yet equally plausible, extremes of the future (Holman and Loveland, 2002). Two additional 'climate only' scenarios are also provided, termed HIGH and LOW, which are directly derived from the 1998 UKCIP HIGH and LOW climate scenarios (see UKCIP, 2001) respectively, and are utilised to distinguish changes attributable to climate only.

In addition to the scenarios described, RegIS developed regional-scale land use change data for East Anglia using regional-scale models which consider future flood extent, changes to agricultural markets and climate change, and are designed to be applied at the five kilometre grid square scale (see Holman and Loveland, 2002). In total, 40 grid cells cover the study area (Figure 3.1). RegIS utilises 1995 (as a baseline) and 2050 as time-points and provides land use change data for all four of the scenarios. The overriding challenge is to determine the spatial location of each land use type (totalling that prescribed by the RegIS data) within each five kilometre square. However, some preparatory stages are required before this issue can be addressed.

2.3. Implementation of the methodology

2.3.1. Developing a baseline land cover map

In order to provide plausible scenarios of how the landscape is likely to respond to the RegIS drivers it was first necessary to develop a baseline 'present day' land cover map of the Broadland study area; this map would be the basis from which the land cover changes could be projected, and provide a means of checking the validity of areal coverages of the different land cover types from the RegIS baseline. A baseline land cover map for 1995 was developed in ArcGIS (ESRI, 2008) utilising two existing land cover/use datasets, respectively, for reference: Land Cover Map 2000 (LCM2000) (Fuller et al. 2002) and the Ordnance Survey's (OS) 1:1250 MasterMap® product (Ordnance Survey, 2009). It is important to note that LCM2000 distinguishes land covers as opposed to land uses due to fact that it is derived from satellite remote sensing (see Fuller et al. 2002). As a result, the OS MasterMap product was adopted to provide additional information on land use.

Table 3.1 describes the method by which each land cover layer was created. To summarise, land covers were identified from LCM2000 and converted from raster to vector format. Then, this vector layer was overlain with the OS Mastermap dataset to assist in identification of field boundaries. Each OS Mastermap polygon was classified on the basis of the LCM2000 categories within it. In total, eight different land cover types were generated: arable; permanent grassland; recreation; roads; uncultivated land; urban; water and woodland (see Table 3.1). These were stored in vector format. To ground-truth the spatial extent of these land covers, 1000 points were randomly generated and the land cover at each point validated by eye against 2004 aerial photography. In total, 88 % of points had the correct land cover. The relatively simple land cover categories used in this study allowed the ground-truthing exercise to be easily undertaken visually using aerial photography alone. However, had a greater number of land cover categories been adopted, the use of field surveys would most likely have been required.

Land cover	Method for creating layer
Arable	**(i)** Combine arable cereals and arable horticulture categories from LCM2000 into a single arable raster layer. **(ii)** Add land parcel boundaries from OS Mastermap. **(iii)** Identify land parcels that completely contain arable.
Permanent grassland	Note: RegIS models land use data for changes in permanent grassland, therefore this category needed to be selected from all grassland types in land use datasets. **(i)** Combine acid, neutral, calcareous and fen, marsh and swamp categories from LCM2000 into a single grassland raster layer. **(ii)** Add land parcel boundaries from OS Mastermap. **(iii)** Identify polygons from OS Mastermap that are acid, neutral, calcareous and fen, marsh and swamp. **(iv)** Combine temporary and improved grassland categories from LCM2000 into single temporary grassland layer. **(v)** Identify land parcels from OS Mastermap that completely contain temporary grassland and remove.
Recreation	Note: Areas used for recreation are difficult to identify from LCM2000 as they are often misclassified as improved/temporary grassland or set-aside grass and therefore it is necessary to use OS Mastermap to identify recreational fields. **(i)** Search OS Mastermap data labels to identify recreational areas. **(ii)** Select land parcels that completely contain labels.
Roads	**(i)** Identify land parcels from OS Mastermap that are either roads, paths or tracks.
Uncultivated land	Note: this layer was created last in the analysis presented here. As well as predominantly containing improved/temporary grasses it also contains all other polygons which could not be assigned another class. **(i)** Combine temporary and improved grassland categories from LCM2000 into a single temporary grassland layer. **(ii)** Add land parcel boundaries from OS Mastermap. **(iii)** Identify land parcels that completely contain temporary grassland. **(iv)** Identify all other remaining areas that have not been assigned an appropriate land cover category.
Urban	**(i)** Combine suburban/rural developed and continuous urban categories from LCM2000 into a single urban layer. **(ii)** Add land parcel boundaries from OS Mastermap. **(iii)** Identify land parcels that completely contain urban.
Water	Note: Due to similar spectral signatures from remote sensing of LCM2000 land cover classes water and woodland are often difficult to distinguish from one another. Subsequently, labels from OS Mastermap data were used to pinpoint areas of water. **(i)** Search OS Mastermap data labels to identify water areas. **(ii)** Identify land parcels that completely contain labels. **(iii)** Combine inland water and sea/estuary categories from LCM2000 into single water layer. **(iv)** Identify any land parcels that completely contain water.
Woodland	**(i)** Combine broadleaved and coniferous woodland categories from LCM2000. **(ii)** Add land parcel boundaries from OS Mastermap. **(iii)** Identify land parcels that completely contain woodland. **(iv)** Remove any extraneous man-made features.

Table 3.1. Method for creating individual land cover layers. LCM2000 class categories referred to relate to LCM2000 Subclasses and Class Number (Level 2) given in Fuller et al. (2002).

The baseline areal coverages (in ha) of the land cover types from the RegIS data were then compared with the distributions of land covers seen within the land cover maps to ensure that results were similar. Evidence suggested that the baseline land cover map was able to represent the baseline RegIS land cover data with a mean difference in total extents of 0.44 % (standard error = 1.49). Land cover map outputs were then converted to raster format at 5 m resolution as the algorithms used by land cover models within the GIS required raster data. This resolution was chosen as the best compromise between fine spatial resolution and manageability of the datasets in the GIS. File size considerations were important as each of the 40 five kilometre square grids that covered the study area initially contained approximately 100 MB of spatial data from the baseline land cover map. This vector to raster conversion process allowed for the development of land cover maps for the 2050 time-point.

2.3.2. Spatial data preparation

For the purpose of localising the 2050 RegIS land use data within each five kilometre grid square, it was necessary to assign each of the land use types that were provided by RegIS (e.g. 28 agricultural crops, set-aside, urban and woodland), to an appropriate land cover category in the baseline land cover map. This was done so that direct comparisons could be made between the eight land cover categories, to identify any significant transitions seen between these two scenario time-points, and so that the identified land cover trends could be projected to the 2100 time-point.

RegIS does not provide data for four of the eight land cover types that were created in the baseline map (recreation, roads, uncultivated land and water). Roads were assumed to remain unchanged. Due to the cellular nature of the land cover model it is not possible to realistically project changes to water and therefore this has not been considered in this study; changes in water extent could be modelled post-process and may then be overlain upon the land cover maps (e.g. Gardiner et al. 2007). Modelling of water level changes within Broadland is currently being undertaken using sophisticated hydrological-based models (Broads Authority, 2007). Further, flood defence policy is also liable to change in the future which may add to the uncertainty of providing local-scale predictions. In a future where there are increasing pressures from agriculture, (i.e. for food production in the RE scenario), it is plausible that uncultivated land will be converted for another land cover (see UKCIP, 2001), and uncultivated land was thus modelled so that it was liable to change in this study.

Storylines for both SESs suggested that an increase in recreational areas may occur as a result of the growing demand for recreational access and leisure pursuits and increasing population (UKCIP, 2001). Accordingly, after consultation of scenario narratives and review of scenario literature, an increase in area of recreational land of 30 % and 10 % was specified under the RE and GS scenarios, respectively. The four remaining land covers (arable, permanent grassland, urban and woodland) were generated by simplifying the multiple RegIS crop categories into a single 'arable' category, whilst permanent grassland, urban and woodland land covers were directly adopted from the remaining categories.

2.3.3. Identification of multiple criteria and allocation of areal totals

At this stage, the land cover totals (in ha) of each of the eight land cover types, for each of the 40 five kilometre grid squares, had been calculated for the year 2050. The next stage of the methodology was to determine the spatial distribution of the land covers. This required the development of a suitability map for each land cover type that identifies the most suitable location. Figure 3.2 outlines the methodology that was developed in order to generate suitability maps, to allocate the 2050 RegIS land cover totals based on these suitability maps, and to identify and project land cover changes to the year 2100. The methodology was implemented using IDRISI Andes GIS v15.01 (Eastman, 2006b). IDRISI was chosen due to its widespread application within the field of GIS-MCDA (e.g. Ceballos-Silva and López-Blanco, 2003; Akgun and Bulut, 2007; Sarptas et al. 2005), its cheaper cost compared to many other packages, and its high ease of use, all of which make it an attractive option for those working with a limited budget.

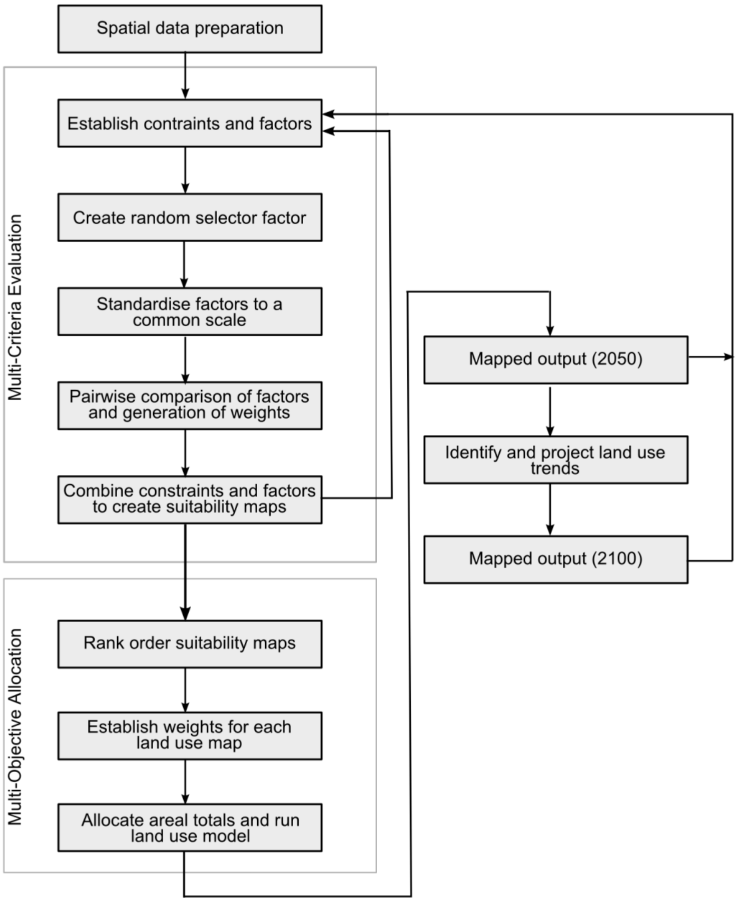

Figure 3.2. Methodological framework for localising land cover data for 2050 and projecting land cover trends to the year 2100 (Source: modified from Eastman et al. 1995, p.544).

In order to produce a suitability map for each land cover it was necessary to first identify criteria which may affect their spatial distribution. These criteria may either be a constraint or factor.

Constraints are areas not suitable for the land cover in question and are Boolean in nature. Factors are generally continuous (e.g. distance or slope gradient) and indicate the relative suitability of different areas. Criteria utilised in modelling land cover data from the RegIS project were adopted for the four RegIS land cover categories by identification via literature review (Table 3.2 provides an example). Raster maps were then created of these criteria (e.g. slope suitability vs. not suitable, agricultural land grade).

Criteria for the remaining four un-modelled categories were also needed so that if any change occurred in their areal extent (be this even a marginal change) their spatial distribution could be adapted accordingly. These criteria were also identified through literature review and exploration of the scenario narratives. For example, in the case of recreation, scenario narratives suggested that areas afforded designated conservation status were unlikely to be converted for recreational purposes in the future, and hence these areas were set as constraints. Factors affecting recreational land included distance from existing recreational and urban areas. The same process of criteria identification was repeated for the remaining unmodelled categories. The raster criteria maps for each land cover were then converted to a common byte scale (0-255) and were standardised using maximum and minimum values as scaling points (Voogd, 1983); this process ensured that both the constraint and factor maps could be combined so that, ultimately, a set of suitability maps could be generated.

When constraints and factors maps were initially combined to develop a suitability map for each land cover there were many cells of very similar suitability. The presence of such tied cells resulted in the random allocation of land covers across rasters when the land cover model was first run. This is illustrated in Figure 3.3 by speckled cells and the incongruent allocation of land covers. Upon further investigation it became evident that this was due to the systematic order (i.e. 'normal raster order' – top to bottom, left to right) in which IDRISI selected, and calculated, new values for cells within raster datasets (see Eastman et al. 1995). Due to this problem, a further variable (termed 'random selector' hereafter) was developed to be used as an additional factor within each suitability map to assist the GIS in selecting between cells of very similar suitability. The result of the introduction of this factor was that there was now reduced likelihood that the GIS would encounter tied cells. To facilitate the production of this factor, a random number generator (Haahr, 2008) was utilised to assign a suitability score (of between 1 and 255) to every cell within each five kilometre square raster grid. The process of creating the random selector factor was then repeated for each land cover type and the maps were standardised using the same process previously described.

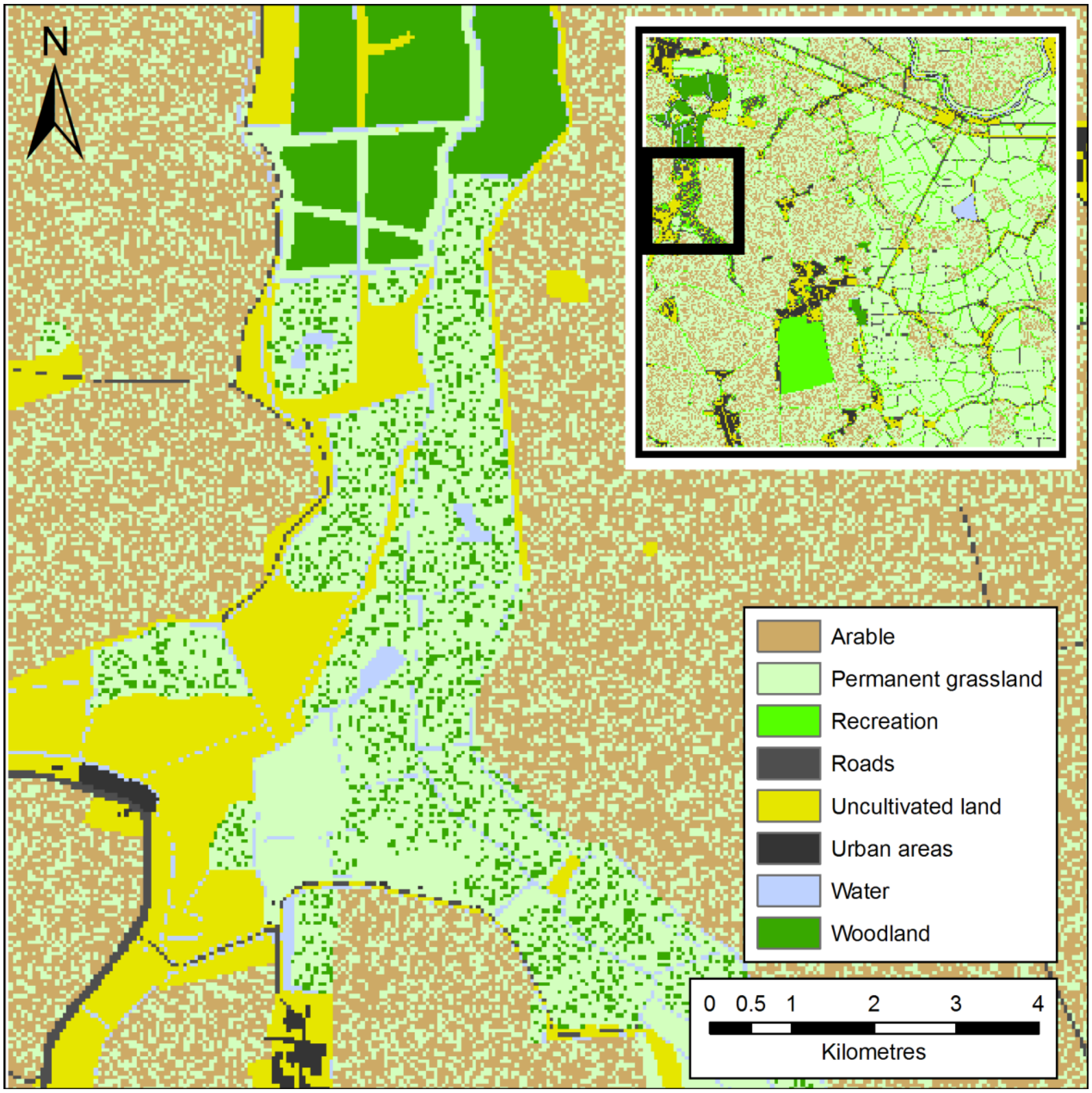

Figure 3.3. Example of spatial incongruence due to cells of similar suitability. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

Before the constraint and factor maps could be combined it was necessary to generate weights for each of the factors; this ensured that different factors would have a varying influence upon the spatial distribution of each land cover type. Stakeholder and expert consultation exercises were not adopted in this work to determine weightings; instead a decision-maker led procedure was used. In order to generate weights, scores (relative numeric values representing importance that sum to 1) were first computed. These were assigned by rank ordering the factors, and scoring each factor accordingly. Factors identified by the RegIS project (see Table 3.2) were given highest priority and therefore received the higher scores. Where factors could not be easily identified, scenario narratives were consulted and lower scores assigned. For example, the RE scenario places particular emphasis upon urban growth, an increasing need for recreational areas and less concern for the environment and conservation (e.g. woodland and permanent grassland). In this instance, these land cover types were more highly valued under the SES, and were therefore assigned a higher score.

In order to produce weightings from the relative scores, a pairwise comparison matrix was generated and weightings were derived, using the GIS, by taking the principal eigenvector of a square reciprocal matrix of the pairwise comparisons (see Saaty, 1977). The relative scoring of factors in the pairwise comparison matrix reflects the relative importance of the criteria in determining suitability for the land cover in question.

A weighting was also required for the random selector factor. A range of different scores were generated and applied to this factor, resulting in different weightings. However, for lower weightings, some spatially incongruent features in map outputs became evident (Figure 3.3). When the higher weightings were assigned to the random factor this had the effect of randomising the allocation of land cover types within the five kilometre grid squares; this was due to its relative strength compared with other factors. Consequently, a mid-range score (thus a medium strength weight - see Table 3.2) was selected for use in the pairwise comparison procedure and was adopted for each of the random selector factors. The pairwise comparison of all factors was then completed in the GIS and weightings were generated (Table 3.2).

A sensitivity analysis of factors was also undertaken in order to establish the impact the introduction of this random factor had upon mapped outputs. To test for consistency, four new random factors were created in the GIS and the land cover model was re-run for the 2050 time-point using the GS scenario areal totals. The influence of the factor was that there were a handful of cells (representing *c*. 5 % of the grid area) which were seen to differ in the land cover type that they were allocated across the four 2050 GS maps. As only 5 % of cells changed their land cover it was deemed unnecessary to run a full Monte Carlo simulation, such as those of Heuvelink and Burrough (1993) and Wu (1998; 2002). Further, given the high spatial resolution and large extent of the datasets, the use of Monte Carlo methodologies would be particularly computationally demanding. Thus, we conclude that the introduction of the random factor enabled the GIS to distinguish between areas of similar suitability with limited impact upon mapped outputs.

Factors	Justification	Score assigned based upon ranking	Weighting
-Existing arable land	-Used in RegIS project; category consists of arable horticulture and cereals, non-rotational horticulture and set-aside grass.	1	0.3166
-Agricultural land grade	-Used in RegIS project. See DEFRA (1988) for agricultural land grade definitions.	2	0.2345
-Presence outside of flood zone	-Used in RegIS project. See Environment Agency (2008) for flood zone descriptions.	3	0.1603
-Existing uncultivated land	-Used in RegIS project; Grass set-aside, rough grass and unmanaged grassland (as defined by LCM2000 – Fuller et al. 2002) all part of this category and all are of sufficient agricultural quality (Grade 3 and above) to maintain arable horticulture or pastoral agriculture if predominantly flooded (DEFRA, 1988); therefore a transition to agriculture is very likely given an increase in demand for suitable land.	4	0.1067
-Random selector	-Developed as a mechanism to assist the GIS in selecting between cells of very similar suitability	5	0.0721
-Existing recreational land	-Recreational land an important component as part of other UK-relevant scenario-based studies (e.g. UKCIP, 2001) and as part of the Broads Plan (Broads Authority, 2007) whereby it is acknowledged as one of four core responsibilities of the authority.	6	0.0504
-Existing permanent grassland	-Category consists of calcareous, acid and neutral grasses and others. All categories reside upon sufficient medium quality (Grade 3 or above) land (as defined by LCM2000 –Fuller et al. 2002) which could support arable horticulture or pastoral agriculture (if predominantly wet); therefore a transition to agriculture is likely given an increasing demand for suitable land.	7	0.0348
-Existing woodland	-Used in RegIS project; category consists of both broad-leaved and coniferous woodland (as defined by LCM2000 – Fuller et al. 2002).	8	0.0246
Constraints	Justification		
-Slopes over 11 %	-Used in RegIS project (see Holman and Loveland, 2002, p.16).	N/A	N/A
-Existing roads	-Roads remain unchanged from baseline extent as they are not modelled by RegIS and any change is subject to considerable uncertainty. More specialist models are required to accurately predict any changes (e.g. Soares-Filho et al. 2001).	N/A	N/A
-Existing urban areas	-Existing urban areas are unlikely to transition to agriculture due to insufficient land quality and extent of development (Holman and Loveland, 2002; DEFRA, 1988). Also, value of land in urban development surpasses its value in agricultural use so a transition to agriculture is unlikely (Capozza and Helsley, 1990).	N/A	N/A
-Existing water bodies	-Areas which are predominantly wet are unlikely to support productive agricultural land (Holman and Loveland, 2002; DEFRA, 1988).	N/A	N/A

Table 3.2. Example of constraints, factors, scores and weights adopted for the purpose of identifying cells suitable for arable land cover under the GS scenario. The scores assigned are generated through ranking each of the factors (Note: 1=greatest score, 9=lowest score) and must be relative values that sum to 1. This process was repeated for each land cover category.

It should be noted that the combined use of jack-knifing and bootstrapping methods (e.g. Rushton et al. 2004; Gibson et al. 2004) as a solution to improving spatial congruency within map outputs may provide an alternative to the approach used here. Both jack-knifing and bootstrapping methods have previously been adopted as tools to measure sample error in a variety of different contexts, including habitat suitability modelling (e.g. Gibson et al. 2004) and environmental pollution (e.g. Baginska et al. 2003). Both methods necessitate multiple sampling of the underlying dataset and offer similar advantages in their ability to generate confidence intervals around data points, and therefore the establishment of a more reliable estimate of sensitivity. However, the methods were not employed here due to their computational demands combined with the large size of the study area. A further consideration was that the IDRISI software used for this work did not have built-in functionality for them.

At this point the constraint and factor maps needed to be combined so that the GIS was able to calculate the suitability of each cell for each land cover type. A number of combination approaches are available; however, Weighted Linear Combination (WLC) is typically used for this procedure (Eastman et al. 1995). For a discussion of the merits of WLC see Eastman (2006a). The technique was selected as the most appropriate combination procedure here because it is a flexible approach which can be considered neither a risk-taking nor risk-averse procedure (Jiang and Eastman, 2000). Individual criteria are able to trade off their qualities; a relatively poor suitability for one factor can be compensated by having a relatively high suitability for another factor, as opposed to cells only being suitable if they meet all or a single criterion (Eastman et al. 1995). The WLC process was applied to combine all constraints and factors to create eight suitability maps (one for each land cover). This process was then repeated for all four scenarios.

In the next stage, each of the land cover suitability maps were rank ordered so that every cell, within each suitability map, was assigned a ranking (a unique numerical value between 1 and 1 million); this procedure assisted the land cover model in selecting the best cells according to their suitability for the land cover type in question. Next, a weighting was applied to each of the ranked land cover suitability maps; this weight determined the precedent for each land cover in cases of tied suitability. The weightings that were assigned to each of the ranked land cover suitability maps (a unique numerical value between 1 and 8) reflected the importance of the particular land cover according to the scenario in question. For example, under the RE scenario, urban land, recreation and agriculture are the most highly valued land cover types whereas woodland, permanent grassland (which contains habitats of conservation potential) and uncultivated land are the least. Consequently, those land cover types which were more highly valued were given a higher weighting and were more likely to be allocated to cells. The ranking and weighting procedures were repeated for each of the suitability maps for each of the scenarios.

In the final stage, areal totals (according to the 2050 RegIS land use data) for each land cover type were specified in the GIS and allocated to the most suitable cells. This stage represented the development of a land cover map for each five kilometre square grid for the year 2050 as a function of the four different scenarios, thus localising the RegIS predictions.

Figure 3.4 provides an example of the type of mapped output developed. This figure depicts all four modelled scenarios, and two clear trends are evident. Firstly, under both Regional Enterprise and HIGH scenarios the areal extent of arable land increases dramatically. This is due to rising pressures upon food production imparted by a growing population and also as a result of an increase in temperature which means that most of the area is now suitable to sustain high value crops (e.g. winter wheat and sugar beet). Secondly, under Global Sustainability and LOW scenarios, permanent grassland is seen to almost double in area from the baseline. The majority of this increase is due to land changing away from arable uses due to the risk posed by flooding. Most of this newly created grassland would be used for grazing.

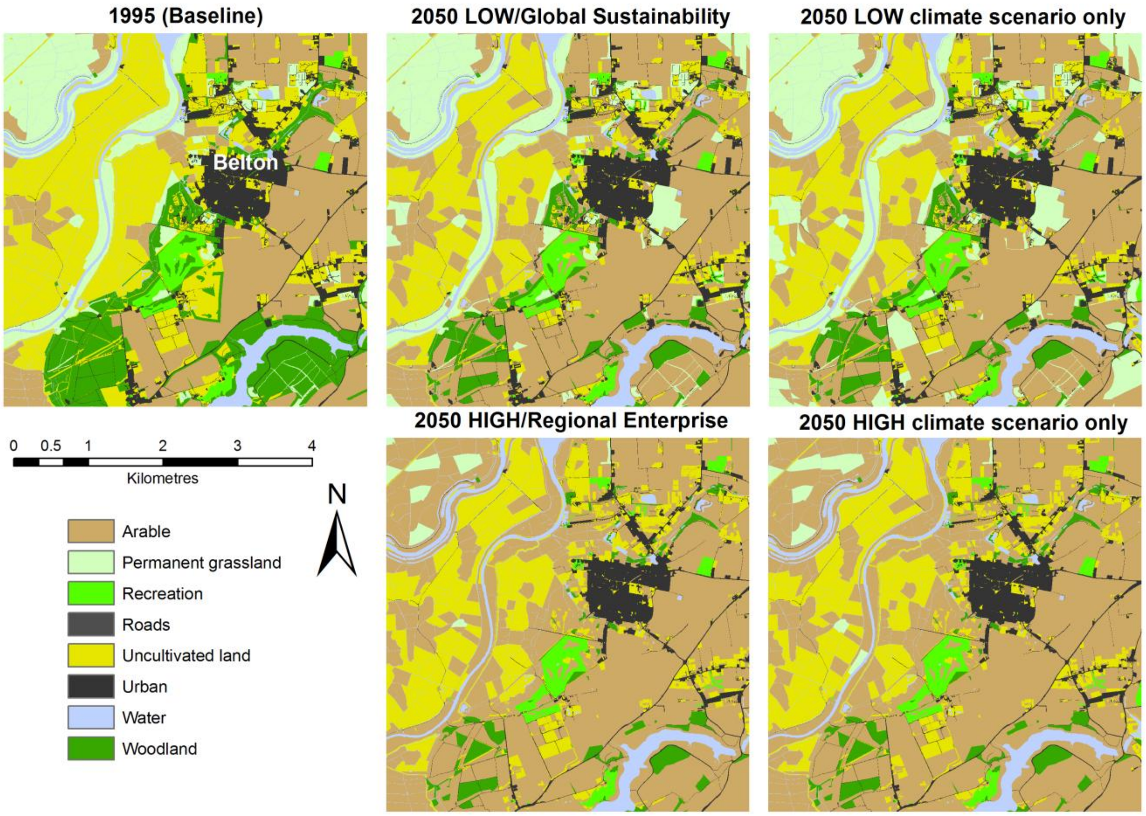

Figure 3.4. Example of 1995 - 2050 land cover change within a five kilometre square grid under four scenarios. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

In order to create land cover maps through to the year 2100, which would assist local decision-makers in understanding the medium- to long-term implications of socio-economic and climatic change upon Broadland, it was necessary to identify any trends between the baseline and 2050 time-point and project these into the future. The next stage of the methodology was implemented to provide that.

2.4. Identify and project land cover trends

The use of Markov Chain Analysis (MCA) has become increasingly prominent within the field of GIS-MCDA (e.g. Weng, 2002; Sun et al. 2007), and the use of Cellular Automata (CA) based models is already well established (Briassoulis, 2000). MCA is a stochastic process whereby the spatial distribution of land covers at a later time-point can be predicted by the distribution at an earlier time-point via the production of a matrix of transition probabilities from each land cover class to every other land cover class (see Weng, 2002). In contrast, CA is a cellular entity that independently varies its state based upon its previous state and the state of its neighbours (see Wu, 1998). One of the key advantages of CA for land cover modelling is that individual cells are considered one at a time (rather than a group of cells being considered as a whole unit) which means that, when CA is incorporated with models of land cover, spatially precise outputs can be generated. Therefore, by combining a CA-based approach with the MCA process (hereafter CA-MCA) the user is able to add a spatial dimension to the modelling process (see Eastman, 1993a). The advantage for cellular models of land cover change, like the one implemented in this study, is that areas closer to existing land covers will have a tendency to change to that particular land cover. Consequently, when projecting land cover transitions between two different time-points, the approach maintains the spatial contiguity of map outputs. A CA-MCA based method was therefore utilised to identify and iteratively project trends seen between the baseline and 2050 time-point to the year 2100. The land cover model was run for 50 iterations (each iteration representing a single year) in order to generate a set of land cover maps for the year 2100 for each scenario.

Figure 3.5 provides an example of the mapped output from the modelling process whilst Table 3.3 provides the areal coverage of each land cover type under all the scenarios. In total, nine land cover maps were produced for each five kilometre grid square, totalling 360 maps under all scenarios and time-points.

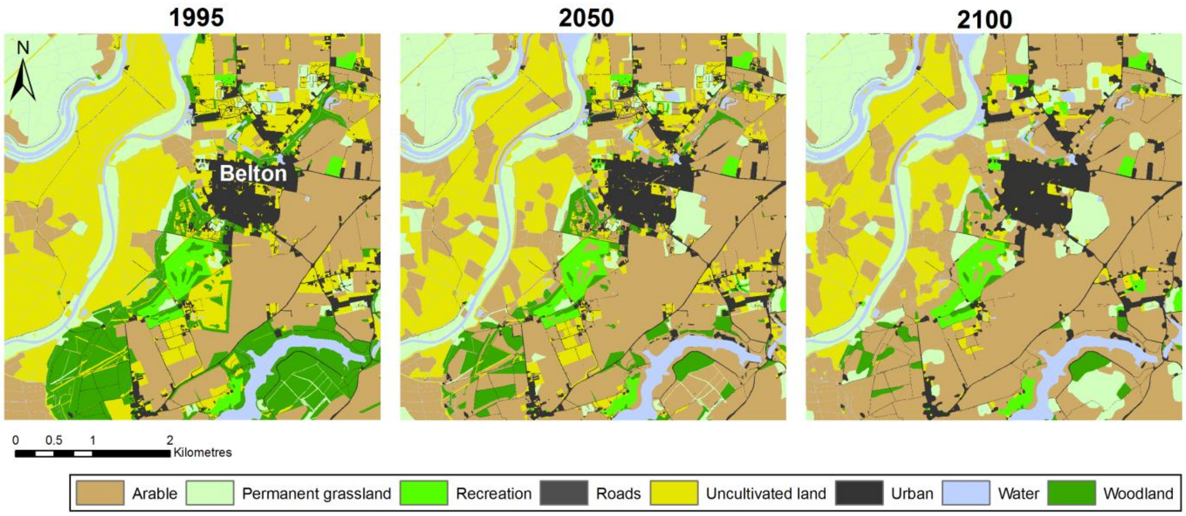

Figure 3.5. Example of 1995 - 2100 land cover change within a five kilometre square grid under the Global Sustainability scenario. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

The increase in area of permanent grassland continues to the year 2100 from 2050 under the GS scenario (Table 3.3) where flood-prone land is largely converted to this category (Figure 3.5). Urban areas in rural locations are also seen to expand from their state in 2050; this is due to urban-to-rural migration where individuals have greater flexibility in their place of work. The agricultural area also continues to decrease to 2100 in the GS scenario, largely due to less pressure from population growth (and therefore reduced food production) and reduced competition in the marketplace, for example from the presence of agricultural subsidies and support measures for farmers. The trend of increasing agricultural area continues under both the HIGH and RE scenarios from 2050 to the year 2100, but to a much lesser extent than observed before, as the amount of land available to sustain agriculture slowly declines and competition for other land covers (e.g. urban areas) increases.

	2050				2100				
Baseline (1995)	LOW	GS	RE	HIGH	LOW	GS	RE	HIGH	Land cover
55477.6	52,284.7	53,713.5	67,268.9	67,511.9	49,697.9	51,761.8	67,928.5	68,751.2	Arable
9988.1	17,766.1	15,732.6	3038.4	4273.2	21,808.6	19,032	3739.5	4770.2	Permanent grassland
702.1	766.6	766.7	816.7	816.9	844.6	840.7	900.4	923.6	Recreation
3008.9	3010.7	3009.6	3004.6	3005.2	3113.9	3110.6	3113.8	3117.4	Roads
7761.9	7029.8	7047.3	6957.2	6960.7	6096.3	6098.1	5657.6	5938	Uncultivated land
7310.4	7427.9	7416.0	7985.3	6452.2	7606.7	7579.9	8569.1	6366.5	Urban
3701.9	3698.8	3697.6	3677.8	3680.0	3813.7	3813	3829	3815.3	Water
7578.9	3545.1	4146.4	2780.8	2829.6	2568	3305.2	1812.7	1869.2	Woodland

Table 3.3. Total areas (ha) of each land cover type for the years 1995, 2050 and 2100 under all four scenarios. Note: GS = Global Sustainability; RE = Regional Enterprise scenario.

3. Discussion

This paper has demonstrated a procedure that enables the output of regional-scale scenarios to be downscaled and represented at a local level, using a combined GIS-MCDA methodology, for the purpose of investigating the medium- to long-term impacts of socio-economic and climatic change upon local landscapes. A case study of the Norfolk Broads was used to illustrate the implementation. A number of contributions and some limitations of the procedure are discussed below.

Key contributions include the reduced need for expert or stakeholder involvement in the modelling process, or for providing input via multiple engagement activities, which are often costly and time-consuming. Although the benefits of stakeholder engagement are documented (e.g. Shackley and Deanwood, 2003), an advantage here is that focus is able to be maintained upon mapped outputs by using scenario narratives and literature review only. This type of approach might hence be particularly appealing to local decision-makers with limited capacity.

The methodology presented here allows the process of assigning weightings to individual factors to be carried out using a series of step-by-step operations which reduces the need for wider input. However, a limitation of this is that some of the decisions that are made might not relate to on-the-ground conditions or the needs of various stakeholder groups. Consequently, it is important that people with local knowledge are involved at some stages in the project to ensure that the outcomes are adequately ground-truthed and are relevant to the local context.

It could be argued that, in achieving the land use totals prescribed by the RegIS data, one is putting the constraint of fitting predicted change or total extent of a land use/cover type before the reality of how suitable that land is to support the land use/cover type in question. For example, if the RegIS land use data for 2050 suggests that there will be a dramatic increase in arable land under the RE scenario in a particular grid, then the GIS will create it somewhere even if it means creating arable on land that has low suitability. Justification to support the presupposition of achieving land use totals prescribed by RegIS might result from the inherent benefits of efficiently, and accurately, replicating already widely adopted regional-scale land use change data at the local-scale, thus providing a tool that allows plausible scenarios and spatially detailed local land use/cover change information to be generated from coarse input data.

One of the novelties of this work was the application of a random selector factor in the generation of land cover suitability maps. This was found to be instrumental in allowing the GIS to create spatially congruent and plausible map outputs. Where differences in mapped outputs resulting from the random selector factor were observed in a sensitivity analysis, they were largely constrained to river valleys. The cause is that areas either side of rivers are naturally of low suitability, possibly due to the threat posed by flooding. We suggest that this is one of the shortcomings of localising more national- or regional-scale data to be applicable within local landscapes, as they do not explicitly allow for such local constraints. For example, in this case, even land of relatively poor suitability (i.e. it is flood prone and therefore of low agricultural grade) is still converted to agriculture due to the requirement of the land cover model to allocate the prescribed amount of arable land according to the 2050 RegIS land use data. Nevertheless, it is evident that the impact of the random selector factor upon the balance of land covers in map outputs is minimal and we propose it as an appropriate method for resolving areas of similar suitability and/or for improving spatial contiguity of mapped data.

A limitation is that some of the criteria used in constraint maps are deterministic. In this work for example slope was modelled as a Boolean indicator (above / below 11 %) before input into the land cover model. An alternative method would be to model such parameters as continuous by specifying a relationship of decreasing suitability (i.e. weighting) with increasing slope as a factor map in the land cover model. Further, it should be noted that the land cover model used here was run for 50 iterations, each representing a single year, with incremental changes in land cover occurring each year. In reality, changes in land cover at the local-scale may be more likely to occur in sudden jumps with intermittent periods of slower growth in between. Nevertheless the timing of these sudden jumps is difficult to predict, and as the focus of this work was on two specific time points rather than a fine-scale temporal evolution of the landscape, the incremental approach was felt to be adequate here.

A further criticism might concern the scenarios chosen for application within the study area. Rising sea levels and competition for upland areas, and the creation of a more connected landscape through the creation of landscape corridors are arguably two equally plausible scenarios for the study area. However, no existing scenario-based project considers these types of changes. This highlights one problem of localising coarser-scale scenarios in that they may well not consider unique components of the landscape of interest. This is particularly the case in Broadland where the area itself is unique. Whilst there is no reason why the types of changes described could not be integrated into existing scenarios, uncertainty in the degree of flood protection likely to be put in place in Broadland meant that this was not attempted here.

Although the principal map outputs of this methodology are deterministic in nature, the underlying assumptions have a range of uncertainties associated with them. The random selector factor could be employed as one tool for communicating the outcome of these uncertainties to decision-makers and non-experts who want to utilise land cover and climate change data for localised studies. Work currently exists which attempts to visually and qualitatively communicate uncertainty in landscape data using a variety of techniques (e.g. Appleton et al. 2004). However, the outputs from the sensitivity analysis presented here could act as an additional platform for visualising uncertainty, specifically with regard to the likelihood that certain land covers may undergo transition in the future.

4. Conclusions

The coarse modelling resolution of some national- or regional-scale scenario-based projects can render outputs inapplicable within local, often environmentally sensitive, landscapes. Improving data resolution allows us to investigate alternative potential futures at greater spatial detail thereby providing vital input into policy and future decision-making. A GIS-MCDA based approach can provide a means of producing maps of future landscapes which are of a high spatial resolution from coarse input data, and hence may form an important input into the landscape planning and management process.

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Chapter 4

Identifying conservation opportunities under future land cover scenarios: a case study of redshank (*Tringa totanus*) and bittern (*Botaurus stellaris*)

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In review with *Journal for Nature Conservation*

Identifying conservation opportunities under future land cover scenarios: a case study of redshank (*Tringa tetanus*) and bittern (*Botaurus stellaris*)

Abstract

Land cover change has resulted in the loss of biodiversity-rich wet grasslands that accommodate a variety of breeding wader species, and an associated reduction in populations has occurred. Future changes in land cover, as a result of climate change or societal shifts will place further pressure on these habitats and make the identification of zones that may be suitable for conservation difficult. Using a case study of the Norfolk Broads (Broadland), this study presents and applies a scenario based methodology to identify areas of conservation potential that may be suitable to support populations of redshank (*Tringa totanus*) and bittern (*Botaurus stellaris*) under future conditions. The study identifies 128 land parcels suitable for arable reversion to grassland for redshank (mean size = 13.2 ha) and 19 for bittern (mean size = 37.1 ha). For bittern, the parcels could support populations of a size that contribute almost 20 % to UK Biodiversity Action Plan (UKBAP) targets, despite utilising just 1.3 % of arable land. These findings highlight our existing capacity to increase breeding wader numbers and may provide useful input into current policy governing nature conservation resources.

Keywords: agri-environment schemes, conservation, land cover change, waders

1. Introduction

Increasing pressures from a range of physical and social drivers mean that the nature of the environment is changing, and one of the key trends is changes in land cover. Socio-economic interactions resulting in land cover change, for example population growth leading to increased demand for food, are expected to place an increasing burden upon natural resources, including species and habitats (IPCC, 2001). It is estimated that as much as 15 million hectares of grassland have been lost over the last 200 years across Europe (Benstead et al. 1999), mainly through conversion to agriculture, with this trend likely to continue. Coupled with these pressures, climate change is expected to result in large-scale modifications to species composition, as well as biodiversity loss (Sala et al. 2000) primarily due to increasing temperatures, changes to precipitation regimes and demands upon water resources (IPCC, 2000). Consequently, there is widespread recognition that we must now begin to prepare for future changes which may have irreversible impacts upon nature conservation resources (e.g. Harrison et al. 2001; 2006).

The UK Government has a range of environmental commitments for safeguarding national nature conservation resources, including the European Union Birds and Habitats Directives (European Union, 1979, 1992). This legislation is in part a response to the Convention on Biological Diversity which encouraged the development of a UK Biodiversity Action Plan (hereafter UKBAP), with emphasis placed upon species and habitats (see UK Biodiversity Group, 1999). However, such conservation commitments have been criticised (see Berry et al. 2001; Hossell et al. 2003; Harrison et al. 2006) as they do not take into account the potential impacts of future change upon natural resources, despite evidence that socio-economic and climatic changes are already altering some sensitive physical and biological systems (IPCC, 2001; Cramer and Whittaker, 1999). For example, several researchers have identified phenological responses to climate change derived from increasing temperatures (Bairlein and Winkel, 2001; Menzel and Estrella, 2001) and earlier onset of autumn and spring conditions (Sparks and Menzel, 2002), as well as changes to flora and fauna distributions (Parmesan et al. 1999). Other studies have identified increasing urbanisation and agricultural intensification as socio-economic responses to changes in land cover (Lambin et al. 2001; Foley et al. 2005).

Widespread agricultural intensification has led to the destruction of biodiversity-rich wet grasslands resulting in severe declines in numbers and distribution of many wading bird species in the UK and throughout Europe (International Wader Study Group, 2003; Wilson et al. 2005). Declines have been attributed to increased predation levels and nest destruction, coupled with reductions in food supply (Newton, 2004). This trend is set to continue over the next century as changes in land cover are expected to be the predominant driver of global biodiversity declines (Sala et al. 2000).

Whilst breeding wader populations have been generally seen to fall in number in recent decades our understanding of how to improve current habitat for waders, including the re-creation and restoration of wet grasslands, has progressed (Eglington et al. 2008b; Gilbert et al. 2005a, 2005b; Smart et al. 2006). Research has suggested that the reintroduction of water into habitats is critical as is the presence of periodic surface flooding (Benstead et al. 1997). In addition, land management initiatives such as agri-environment schemes have been employed as part of the EU's Common Agricultural Policy (CAP), and its subsequent reforms, to encourage farmers to manage their land for waders, for example via reduced livestock densities or ditch excavation (Hodges, 2005). More recently, reversion of arable land into wet grassland in the UK has become increasingly commonplace, driven by reforms of the CAP (Harrison et al. 2006). The majority of these reversion sites have recorded significant increases in breeding wader population densities (see Eglington, 2008a) and hence may offer a possible solution to reversing declines in wader numbers.

At the same time that our understanding has improved of how to manage landscapes to encourage increases in breeding wader numbers, studies have been implemented to identify and prioritise areas for conservation, many of which have been undertaken using a Geographic Information System (GIS). These include empirical analyses which have used predictive models to target potentially suitable habitats (Bayliss et al. 2005; Guisan and Zimmermann, 2000) and stakeholder and expert consultations which delineate suitable land parcels given sufficient water level management or income from targeted agri-environment schemes (e.g. Broads Authority, 2004). Other studies have developed future scenarios that predict the potential impacts of land cover and climatic changes upon biodiversity richness and abundance (e.g. Sala et al. 2000; Chapin et al. 2000), discussed implications for conservation policy (e.g. Hossell et al. 2003; Harrison et al. 2006) and made attempts to identify current conservation 'hot spots' for prioritisation (e.g. Myers et al. 2000; Ginsberg, 1999).

Despite the abundance of relevant studies, there are a number of disadvantages associated with the types of targeting approaches generally used. Perhaps most important is the fact that they often assume habitats will remain static or that any variation will adhere to recent trends, even though dramatic shifts in the location of suitable habitat have occurred and are expected to continue in the future (e.g. Hossell et al. 2003; Harrison et al. 2001).

The Broads Authority, the statutory authority tasked with managing the Norfolk Broads wetlands in East Anglia, UK, along with a number of statutory and voluntary organisations (e.g. Norfolk Wildlife Trust and Natural England) has recently identified approximately 2000 ha of land which may provide future opportunities for conservation (see Broads Authority, 2004). These land parcels, termed Wetland Enhancement Areas, have been identified using input from flood models and local expert consultation with focus upon the identification of parcels likely to be inundated by future flooding. Whilst the use of modelling and consultation provides some forecasting functionality, more general changes in the landscape which may affect the land covers present across the parcels are particularly difficult to quantify. Consequently, there is benefit in developing models of future land cover change to help identify land areas that might present conservation opportunities and perhaps warrant protection. The outputs of such a process may assist in planning for future threats upon breeding wader species, as well as representing an opportunity for conservation based upon known habitat preferences.

Using a case study of the Norfolk Broads, an environmentally sensitive and internationally important wetland habitat, this research seeks to explore the conservation potential of breeding wader species by utilising a model of future land cover change to identify areas of potentially suitable habitat. Firstly, future land cover scenarios are described. Rationale is then provided for the selection of focal species before a range of management options available to land managers are identified which may be utilised to facilitate the creation of suitable habitat. Implementation of the methodology is presented with the aim of identifying land parcels that may be suitable for the conservation of two breeding wader species; the redshank (*Tringa totanus*) and bittern (*Botaurus stellaris*) in Broadland. Finally, the conservation potential of the study area is evaluated, and the benefits and limitations of the approach described are examined.

1.1. Land cover scenarios

Scenarios are often used as a tool to explore a range of plausible futures and typically describe future changes in land cover (IPCC, 2000). A range of projects exist that provide scenarios which may be adopted for investigating the consequences of future land cover change upon species and habitats. These projects are at diverse spatial scales, including European e.g. IPCC Special Report on Emissions Scenarios (IPCC, 2000) and ATEAM (Schrőter, 2004); national e.g. UKCIP (Hulme and Jenkins, 1998; Hulme et al. 2002) and regional e.g. RegIS (Regional Climate Impact Studies in East Anglia and North West England – Holman and Loveland, 2002) and REGIS2 (Holman et al. 2008). In addition, they may provide quantitative datasets, derived from purpose-built models, which supply GIS-developed gridded cells of land cover data at a coarse spatial-resolution (e.g. RegIS).

We have recently developed a series of GIS-based methodologies that downscale coarser-resolution scenario outputs, including land cover data, to local landscapes (see Munday et al. 2010). We suggest such approaches are particularly relevant to decision-makers working at a highly localised scale, such as that of individual land parcels, as they provide high resolution spatial data and localised scenarios of future change. Consequently, the case study presented here adopts the scenarios and mapped outputs described in our earlier work. We provide a brief description of the datasets here, referring readers to that manuscript for full explanation of their development.

In total, four scenarios for which gridded land cover data were available were adopted from the RegIS project (see Holman and Loveland, 2002). We produced a set of land cover maps for the years 1995 (the baseline land cover map) and 2100 (that used by RegIS) for the Broadland study area. Maps were output as five kilometre grid squares and land cover changes for eight categories (arable land, permanent grassland, recreation, roads, uncultivated land, urban, water and woodland) were modelled. One of the original scenarios considered both socio-economic and climatic changes that might present conservation opportunities and it is this that we utilise in the work here. The Global

Sustainability scenario (related to the UKCIP scenario of the same name) characterises a future world driven by a number of key drivers including agricultural policy, climate change and economic development between a baseline of 1995 and the year 2100; it was this latter year that is the focus of the predictive modelling presented in this work. Changes due to climate were derived from 1998 UKCIP LOW climate scenario (see UKCIP, 2001; Hulme and Jenkins, 1998).

The Global Sustainability scenario represents a world in which conservation of biodiversity is paramount and economic growth is afforded less importance than environmental sustainability (for comprehensive storylines and narratives see UKCIP, 2001; Holman and Loveland, 2002 and Shackley and Deanwood, 2003). Modelled outputs for this scenario are characterised by a significant increase in permanent grassland as focus shifts away from intensive arable production (see Table 4.1). This is due to reduced population growth, and increasing flood risk coupled with changes to agricultural subsidy payments which all act to encourage conservation of biodiversity. It is thus likely that the land cover changes depicted in the Global Sustainability scenario, specifically an increase in permanent grassland, might represent an opportunity for conservation for breeding waders.

Land cover	Baseline	Global Sustainability
Arable land	55,478	51,762 (-6.7)
Permanent grassland	9988	19,032 (+90.5)
Recreation	702	841 (+19.8)
Roads	3009	3111 (+3.3)
Uncultivated land	7762	6098 (-21.4)
Urban	7310	7580 (+3.7)
Water	3702	3813 (+2.9)
Woodland	7579	3305 (-56.4)

Table 4.1. Areal coverage (in hectares) of eight land cover categories under the Global Sustainability scenario for the year 2100. Percentage change values (+/-) from the baseline (the year 1995) are given in brackets.

1.2. Focal species

The focal species were the redshank (*Tringa totanus*) and the bittern (*Botaurus stellaris*). Both waders have an association with grassland habitats (specifically lowland wet grasslands) and have suffered significant declines in the UK over the last 25 years (Amber and Red status, respectively - BirdLife International, 2004). The bittern is listed as ‘priority concern’ in the Local Biodiversity Action Plan (hereafter LBAP) for neutral grasslands and grazing marsh (Broads Authority, 2009) and is an important species for large-scale wetland conservation in Britain (Hawke and Jose, 1996; White and Gilbert, 2003). The bittern has experienced recent increases in number yet is expected to remain increasingly sensitive to changes in habitat availability (Gilbert et al. 2010). A target of 190 birds by the year 2030 has been set as part of the UKBAP, an increase from just 60 birds in 2010 (Wotton et al. 2010). The bittern is also a locally significant species as it is recognised as an iconic winter migratory inhabitant of Broadland's wet grasslands (Moss, 2001). Redshank were once very abundant, and are still relatively so, but populations have declined and are of concern (Wilson et al. 2004). The issue for redshank therefore is not one of threat of extinction but the potential loss of the species from areas of the UK.

1.3. Land management options to provide suitable habitat

Despite falling populations, a variety of land management options may be implemented to improve breeding wader numbers, although appropriate strategies will differ for the two case study species. For example, undertaking relatively moderate or low-intensity land management options (e.g. grazing at low densities or excavating wet features) on arable farmland can yield significant increases in redshank populations (Smart et al. 2006). In contrast, managing agricultural land for bittern requires much more intensive measures including raising water levels and creating reedbed (Gilbert et al. 2007). Consequently, the study presented here envisaged two scenarios; 'moderate management' for redshank and 'maximum management' for bittern. These are representative of the current two-tiered Environmental Stewardship payment scheme implemented within England, comprising Entry Level Stewardship and Higher Level Stewardship. Corresponding management options available to farmers (see Natural England, 2005) were associated with each scenario and these are given in brackets in the descriptions below.

For the purposes of this work, our moderate management scenario involves restoring wet permanent grassland through re-wetting (option HK11) and reduced grazing of livestock (options HK9/HK10) to less than 0.75 Livestock Units ha^{-1}. Minimal water level management within ditches is required (dependent upon site-specific topology and water regime) and shallow wet features (such as rills) are introduced (options HK9/HK10). The majority of these management options are available to farmers under Higher Level Stewardship, but some under Entry Level Stewardship, may create conditions favoured by redshank. In contrast, our maximum management scenario involves the creation of reedbed (*Phragmites australis*) via inundation (option HK5). A much greater degree of water level management is required to maintain 30 cm summer water depth (option HQ5) and ditch networks are restored (options HQ3/HQ13). Some amount of excavating may also be necessary to form areas of higher ground and for the creation of areas of shallow open water (option HQ5); these management options, which may create conditions favoured by bittern, are available entirely under Higher Level Stewardship.

2. Case Study Methodology

2.1. Study area

The case study was conducted within the Norfolk Broads (Broadland), East Anglia, UK, covering an area of approximately 95,000 ha (see Figure 4.1). The Broadland landscape comprises shallow lakes (broads) and rivers, grazing marshes, fen and woodland, as well as intensive arable lands that support numerous threatened and scarce species of flora and fauna of high conservation concern. Broadland is home to a variety of wader species, including redshank and lapwing, and is one of only a handful of UK localities with booming (singing) male bittern (Gilbert et al. 2005b). There is good scientific understanding of the ecology of Broadland (Cowie et al. 1992; George, 1992; Moss, 2001) and studies detailing its unique biodiversity and landscape character (Countryside Commission and English Nature, 1996). However, pressures for change (e.g. from tourism and recreation and climate change) mean that the landscape that we see today faces conflicting demands, particularly with regard to its sensitive species and their habitats.

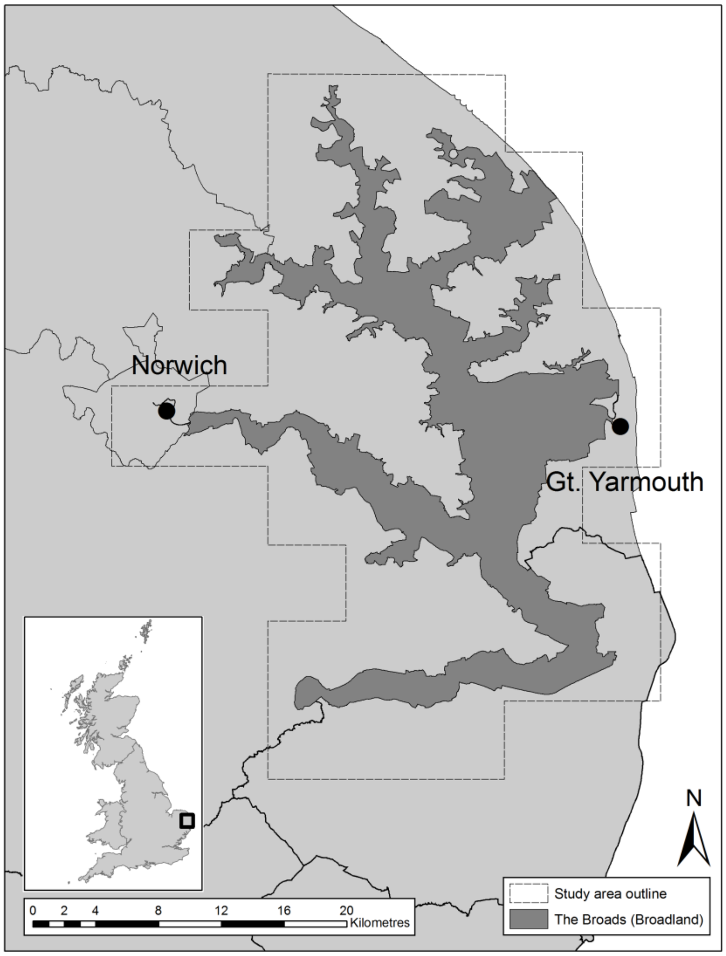

Figure 4.1. The Broadland study area. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

2.2. Defining criteria

The first stage in this work involved the definition of a set of criteria that may be used to identify suitable habitat locations. Table 4.2 provides a summary of the criteria adopted for delineation of land parcels of suitable habitat for both breeding wader species and to map habitat preferences for bittern.

	Redshank (moderate management scenario)	Bittern (maximum management scenario)
Site potential	-Minimum land parcel size = 5 ha -Of low agricultural land grade (Grade 3 or below) -Presence of an existing Environmental Stewardship agreement	-Minimum land parcel size = 20 ha -Of low agricultural land grade (Grade 3 or below) -Presence of an existing Environmental Stewardship agreement -Close to an existing nature reserve
Species habitat preference	-Wet grassland	-Water no deeper than 20 cm and within 30 m distance from reed edge (‘reed edge’) -Water no deeper than 20 cm (‘shallow water’)[a] -Water deeper than 20 cm (‘deep water’)[a] -Un-flooded land (‘scrub’)

[a] Collectively referred to as ‘open water’ in the text

Table 4.2. Criteria used to delineate land parcels of suitable habitat. Habitat preferences of bittern were compiled from Gilbert et al. (2005a).

The primary criterion selected for the identification of suitable sites was the presence of wet grassland. The size of individual land parcels was selected as the second most important criterion. The minimum habitat size needed to sustain redshank and bittern populations varies and reflects differing species’ requirements for prey and nesting areas for the rearing of chicks (Gilbert et al. 2005a; Wilson et al. 2004). Studies were examined which provided estimates of redshank population densities from numerous arable reversion sites in the UK (see Smart, 2005), several of which are located within East Anglia. Values range between 0.1 to 0.6 pairs ha^{-1}. For the purposes of this study, a figure of 0.2 pairs ha^{-1} (equivalent to a minimum land parcel size of five hectares) was selected as the most appropriate value as this was same as that recorded in Holkham (north Norfolk) where Environmental Stewardship prescriptions have been implemented that most closely reflect those described in our moderate management scenario for redshank (Smart, 2005).

In the case of the bittern, there is less consensus regarding optimal parcel size due to the species’ secretive nature and large migratory range (Wilson et al. 2004). For this work, a value of 0.05 pairs ha^{-1} (equivalent to a minimum land parcel size of 20 ha) was selected under our maximum management scenario as suggested by other researchers (Gilbert et al. 2005a; Simon Wotton and Norman Sills, RSPB, pers. comm.).

In terms of the other criteria in Table 4.2, it is likely that agricultural land of low grade (Grade 3 or below – DEFRA, 1988) will benefit most from entry into Environmental Stewardship due to its lesser quality and lower profitability to farmers. The presence of any existing Environmental Stewardship agreement(s) across land parcels, particularly those that comprise low-intensity land management prescriptions (e.g. Entry Level Stewardship), can provide insight into the potential benefits that may be a realised from implementation of more intense options (i.e. Higher Level Stewardship). Also, it is evident that land parcels closest to existing nature reserves might be more preferable sites than those further away due to favourable habitat conditions provided by managed sites and the presence of some core populations in these areas (Tyler et al. 1998). Therefore agricultural land grade, entry into any Environmental Stewardship agreements and distance from existing nature reserves are included as additional criteria to aid selection of the most suitable sites.

Whilst implementation of the land management options described above would be generally accepted as providing suitable conditions for redshank under the moderate management scenario (e.g. Smart et al. 2006; Wilson et al. 2004), bittern tend to be more fastidious in their selection of habitat. As a result it was necessary to define additional criteria for this species. These were water which is no deeper than 20 cm and within 30 m distance from reed edge (hereafter ‘reed edge’), water which is no deeper than 20 cm or water which is deeper than 20 cm (hereafter ‘shallow water’ and ‘deep water’ respectively but collectively referred to as ‘open water’) and the presence of un-flooded land (hereafter ‘scrub’) (see Gilbert et al. 2005a).

2.3. Identifying land parcels for breeding waders and mapping habitat preferences for bittern

Figure 4.2 provides an overview of the methodological stages utilised for the identification of suitable land. For the purposes of this work, land cover data was stored as a regular (raster) grid comprised of five metre squares and a GIS (IDRISI Andes v15.01 – Eastman, 2006) was used for analysis.

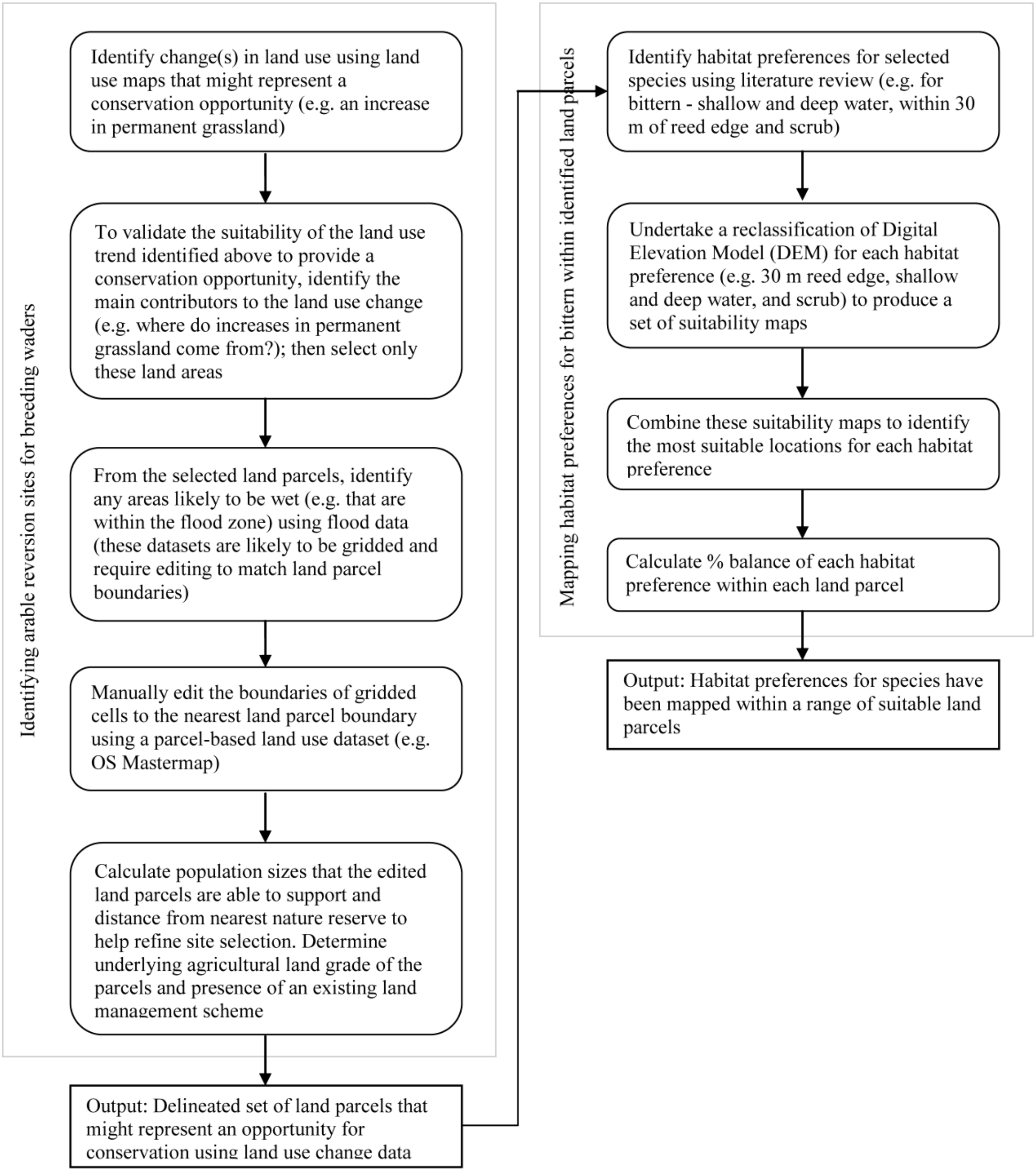

Figure 4.2. Methodological framework for identifying land parcels of conservation opportunity and for mapping habitat preferences.

The first stage of the methodology required the identification of a change in land cover that might represent an opportunity for conservation under both land management scenarios. Given the focus upon implementation of agri-environment scheme options on arable land, a land cover transition from this category to a more biodiversity-rich category, for example permanent grassland, was considered as providing the key potential conservation opportunity. It was thus necessary to identify the land cover categories that most contributed to this transition. If, for example, arable land was to emerge as the greatest contributor to increases in permanent grassland it was likely that these new areas of permanent grassland (i.e. those areas that transitioned to permanent grassland but were not this land cover type at baseline) may benefit from implementation of Entry Level Stewardship and/or Higher Level Stewardship options. Thus, the total area (in hectares) of each land cover type that contributed to changes in permanent grassland was calculated by comparing the spatial extent of each land cover between the two socio-economic scenario time-points (1995 baseline and the year 2100). Results were mapped in the GIS.

The next stage involved refining the range of selected sites by identifying those areas of new permanent grassland that were most likely to be wet, and therefore, provide the most suitable habitat for the two species. A flood map, derived using a model of Broadland's river systems and elevation data, was used for this purpose (Broadland Environmental Services Limited, 2009). The map depicts inundation from fluvial flooding (tide is assumed to be at mean level) in the form of 50 m grid squares and represents a 50-year return period flood event. It was used to identify areas of grassland that would be liable to flooding and therefore potentially wet.

One of the problems of utilising gridded flood model data is that the derived boundaries of any suitable areas will often not match real world boundaries, such as those of fields or land cover transitions. Therefore, a parcel-based land cover dataset (OS Mastermap) was utilised to provide information on the location of boundaries, and the spatial extent of parcels of land was modified to match these boundaries, ensuring this process did not introduce any areas of land that would not be wet.

In the next stage, population sizes of redshank and bittern that the identified land parcels could sustain were estimated so that those potentially able to support the greatest populations could be identified. Population sizes were calculated for each land parcel by multiplying wader density values (0.2 pairs ha^{-1} for redshank and 0.05 pairs ha^{-1} for bittern) by the land parcel size (in hectares). Land parcels not meeting minimum size requirements were removed. The centre-point of each of the derived land parcels was then utilised to calculate straight-line Euclidean distances from the nearest nature reserve. A map of existing National Nature Reserves was adopted for this purpose (Natural England, 2010b). These centre-points were also utilised to determine the presence of any existing Environmental Stewardship agreement(s). To achieve this, each of the points was input into Natural England's 'Nature on the Map' service (Natural England, 2010c) and the presence of any scheme(s) recorded. The agricultural land grade of each of the land parcels was determined by overlaying

DEFRA's agricultural land classification dataset (see DEFRA, 1988). Completion of this stage represented the delineation of land parcels suitable for either redshank or bittern.

In the final stage, each of the four additional habitat preferences of bittern was mapped within the delineated land parcels to refine site selection for this species. To achieve this, a simple reclassification of the Digital Elevation Model (DEM) was undertaken using the criteria provided in Table 4.2. Firstly, areas below 0 cm elevation were assumed to be open water, with shallow water areas defined as -20 – 0 cm and deep water -20 cm or above (Gilbert et al. 2005). Next, suitable areas for reedbed were delineated as those where the water depth did not exceed 20 cm and the distance from the water's edge was no greater than 30 m (based on Gilbert et al. 2005). Any remaining locations were assumed to be scrub. The composition of each habitat preference within each land parcel was then calculated by summing the total area (in hectares) of each key habitat type; composition was then expressed as a percentage of total land parcel area.

3. Results

Some 1176 ha (or 1532 individual land parcels) of wet permanent grassland were initially identified as providing potentially suitable land under both land management scenarios. This value increased to 2120 ha (or 1032 land parcels) after modifications to parcel boundaries to make them congruent with real world boundaries. Approximately 432 ha (or 1992 individual land parcels) were then subsequently removed where they were less than the minimum size requirement for redshank. As a result, in our moderate management scenario for redshank, 128 individual land parcels remained suitable totalling 1688.5 ha (mean parcel size = 13.2 ha, range = 5 - 87.9 ha, s.d. = 12.2); this represents just 3 % of arable land area within Broadland. Of this, around 95 % of the derived parcels were located upon grade 3 agricultural land with the remainder located upon grade 4.

Redshank density values indicated that approximately three-quarters of these land parcels could support up to 3 pairs ha $^{-1}$, making the maximum number of birds that the land parcels could sustain at 338. This represents a population increase within Broadland of approximately 25 % compared to 2002 (Wilson et al. 2005).

Under our maximum management scenario for bittern, approximately 1365.4 ha (or 1011 individual land parcels) were unsuitable because they were less than the minimum size requirement. As a result, 19 individual land parcels remained suitable, totalling 704.7 ha (mean parcel size = 37.1 ha, range = 21.2 - 87.9 ha, s.d. = 15.6); this represents approximately 1.3 % of arable land within Broadland.

All of the derived land parcels for bittern overlain grade 3 agricultural land and ninety percent of land parcels were already in some form of Environmental Stewardship agreement. Two of the sites were currently owned by a conservation body; The Norfolk Wildlife Trust. In addition, eighty-five percent of sites were located within 6 km of existing nature reserves (mean = 6.6 km, range = 1.1 – 11.4 km, s.d. = 2.4). Calculated density values for the land parcels (mean = 1.9 pairs ha^{-1}, range = 1.1 - 4.4 pairs ha^{-1}, s.d. = 0.8) suggested that approximately three-quarters of the sites could support up to 2 pairs ha^{-1} given implementation of appropriate land management options, making the maximum number of birds that the land parcels could sustain at 35. This represents approximately a one and a half-fold population increase in Broadland and sums to approximately 18 % towards the UKBAP target for this species (UK Biodiversity Group, 1999). Figure 4.3 illustrates these outputs by providing an example of some of the land parcels identified under the moderate and maximum management scenarios.

Table 4.3 provides the areal extent of each of the four habitat preferences of bittern and associated population sizes for individual land parcels that contained suitable compositions of habitat. Scrub tended to occupy the largest area within land parcels (mean = 17.6 ha or 48.2 % coverage of land parcel area across all sites, range = 7.3 ha or 26.1 % to 33.1 ha or 72.6 %, s.d. = 12.1) with reed edge (mean = 9.2 ha or 25.2 %, range = 4.9 ha or 5.6 % to 12.2 ha or 44.1 %, s.d. = 11.4) and open water habitats (mean = 9.8 ha or 25.3 %, range = 1 ha or 4 % to 18.4 ha or 68.8 %, s.d. = 17.9) almost equal in extent.

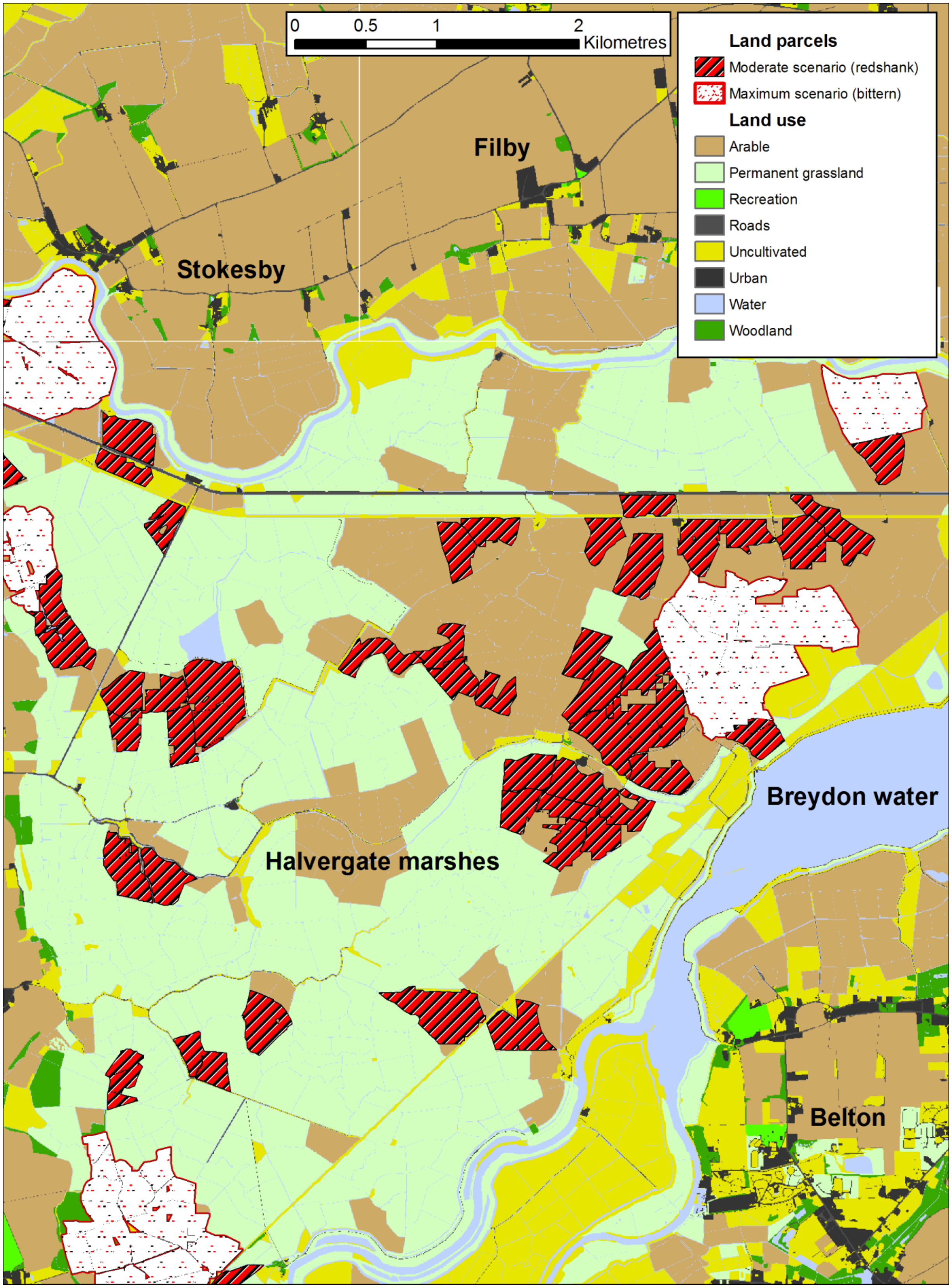

Figure 4.3. Example showing land parcels suitable for redshank and bittern under two management scenarios. Land cover data is from the baseline (1995) time-point.

Land parcel	Easting	Northing	Area Reed edge	Area Shallow water	Area Deep water	Area Open water	Area Scrub	Total area	Estimated population	Management options	Distance to NNR (km)
1	637234	316737	4.2 (12.7)	0.0 (0.0)	16.3 (48.7)	16.3 (48.7)	12.9 (38.7)	33.4	1.7	ESA	1.1
2*	639261	314449	12.2 (44.1)	0.4 (1.3)	3.7 (13.2)	4.1 (14.5)	11.5 (41.4)	27.8	1.4	ELS / HLS	3.4
3*	640577	313457	10.0 (35.7)	0.3 (1.0)	1.6 (5.6)	1.9 (6.6)	16.2 (58.0)	27.9	1.4	ELS / HLS	4.1
4	642843	310203	5.3 (21.3)	0.3 (1.0)	5.4 (21.9)	5.7 (22.9)	13.7 (55.8)	24.7	1.2	ELS	7.8
5	642834	309743	12.7 (34.1)	0.7 (1.8)	11.7 (31.4)	12.4 (33.2)	12.2 (32.7)	37.4	1.9	ELS / HLS	7.7
6	648644	309555	7.3 (27.3)	0.8 (3.1)	0.2 (0.9)	1.0 (4.0)	18.4 (68.8)	26.8	1.3	ESA	11.2
7	642655	308582	4.7 (19.6)	<0.1 (<0.1)	7.4 (30.8)	7.4 (30.8)	12.0 (49.6)	24.2	1.2	None	6.8
8	647840	308022	10.7 (23.5)	0.9 (2.0)	0.9 (2.0)	1.8 (4.0)	33.1 (72.6)	45.6	2.3	None	11.4
9	647562	307622	16.3 (33.1)	2.0 (4.0)	0.0 (0.1)	2.0 (4.1)	31.1 (63.1)	49.4	2.5	ESA	11.0
10	635933	304090	2.0 (7.2)	0.0 (0.0)	18.6 (66.7)	18.6 (66.7)	7.3 (26.1)	27.8	1.4	ELS	1.2
11	643452	303939	24.2 (42.0)	2.1 (3.6)	10.7 (18.6)	12.8 (22.2)	20.7 (35.9)	57.6	2.9	ESA	6.2
12	643663	303387	16.1 (38.3)	1.3 (3.0)	4.1 (9.7)	5.4 (12.7)	20.6 (49.1)	42.0	2.1	ESA	6.5
13	642954	302087	5.0 (14.7)	0.1 (0.2)	11.8 (34.5)	11.9 (34.7)	17.2 (50.7)	34.1	1.7	ELS / HLS	6.1
14	643523	301825	2.6 (11.1)	0.0 (0.0)	10.6 (45.3)	10.6 (45.3)	10.2 (43.6)	23.3	1.2	ELS / HLS	6.6
15	641253	301814	4.0 (19.1)	0.1 (0.3)	5.6 (26.3)	5.7 (26.3)	11.5 (54.4)	21.2	1.1	ESA	4.6
16	640985	301242	11.8 (24.5)	0.2 (0.4)	17.9 (37.0)	18.1 (37.4)	18.4 (38.1)	48.3	2.4	ELS / HLS	4.6
17	641897	301067	4.9 (5.6)	0.0 (0.0)	46.8 (53.3)	46.8 (53.3)	36.2 (41.2)	87.9	4.4	ELS / HLS	5.4
18	641423	300332	11.2 (29.2)	1.0 (2.7)	11.1 (29.1)	12.1 (31.8)	14.9 (39.0)	38.2	1.9	ELS / HLS	5.4
19	648353	295870	9.8 (35.8)	1.4 (5.2)	0.4 (1.5)	1.8 (6.7)	15.7(57.7)	27.2	1.4	ELS / HLS	13.7

*currently managed by a conservation body (Norfolk Wildlife Trust). Notes: Estimated population (number of birds). NNR = National Nature Reserve, ESA = Environmentally Sensitive Area, ELS = Entry Level Stewardship, HLS = Higher Level Stewardship. All land parcels are present upon grade 3 agricultural land.

Table 4.3. Derived land parcels suitable for bittern. Total area covered (in hectares) of four habitat preferences and calculated population densities. Percentages of the total area identified are given in brackets.

4. Discussion and conclusions

This study has developed and implemented an approach that allows potentially suitable land parcels for the future conservation of two breeding wader species (redshank and bittern) to be identified under a scenario of environmental and societal change. Two levels of intervention were envisaged, one for each species, that represented implementation of different tiers of agri-environment scheme options (Entry Level Stewardship and Higher Level Stewardship) available to farmers. Due to the fastidious habitat requirements of bittern four additional habitat preferences important to this species were also mapped within land parcels.

This work has illustrated how it is possible to map potential conservation opportunities that might arise from future changes in land cover, the outputs of which may provide input into current conservation policy governing nature conservation resources and may help to identify areas where the implementation of land management options for waders could be most beneficial. The land parcel-scale outputs could also provide a useful input into studies of habitat fragmentation and connectivity (e.g. Bodin, 2009) and for biodiversity impact assessment (e.g. Taylor and Grant, 2004). Perhaps most importantly, the implemented methodology and derived land parcels demonstrate the potential to provide large areas of suitable habitat for breeding waders which may help reverse long-term declines in population and contribute towards UKBAP targets.

Whilst core (managed) population centres (particular for bittern) become increasingly vulnerable to environmental changes (e.g. sea level rise - Minsmere, Suffolk), it is acknowledged that we must now begin to focus upon providing other compensatory habitats inland (Gilbert et al. 2010). Our findings indicate that large land areas currently exist which may provide opportunities for significant improvements in breeding wader numbers (particularly bittern) within Broadland. The majority of this land is of low agricultural grade and likely to be susceptible to flooding (Munday et al. 2010), meaning that it is particularly suitable for reversion. In addition, the majority of delineated land parcels are currently in low-intensity Environmental Stewardship agreements (i.e. Entry Level Stewardship) and may benefit from more intense levels of land management in Higher Level Stewardship. Thus if funding of Higher Level Stewardship agreements were to increase then widespread improvements in populations of breeding waders may be further achievable.

There are a number of limitations to the methodology presented. A criticism might concern the plausibility of converting such large areas of productive arable land (comprised predominantly of cereals) to grazed wet permanent grassland as predicted by the RegIS data and land cover model (see

Munday et al. 2010). Indeed, one of the underlying limitations of the RegIS data is that it does not address the issue of major capital changes required when switching between different types of farming, instead determining the type that is profitable within the socio-economic scenario (Holman and Loveland, 2002). Therefore, whilst the derived land parcels may potentially provide suitable habitat for breeding waders, and hence benefit from Environmental Stewardship options, many of the proposed prescriptions necessitate some quite substantial changes to current land management practises.

In addition, studies have shown a willingness amongst Broadland's farmers to implement many of these prescriptions (e.g. Eglington, 2008a) yet the success of such schemes is dependent upon them remaining accessible and profitable to farmers (Reid et al. 2007). Land managers must therefore often make choices between the income that they might receive from any agri-environment scheme, the income one might receive from farming the land and the availability of land area (Dwyer, 2005). Despite the fact that all of the derived land parcels are located within Higher Level Stewardship target areas (see Natural England, 2010a) recent fluctuations in cereal crop prices (e.g. the threefold increase in wheat prices in 2007 – Mongabay, 2010) may further increase the attractiveness for farmers' to return to arable cropping, particularly if prices begin to rise again as at present (United States Department of Agriculture, 2010). Consequently, whilst it is clear that large-scale arable reversion is potentially possible within Broadland, the degree to which land managers choose to implement options for breeding wader species remains uncertain. This is more so given uncertainty surrounding Higher Level Stewardship budgets following further reforms of the CAP that are due in 2013 (Buckwell, 2008; DEFRA, 2010).

A further criticism of the methodology might concern the choice of socio-economic scenario that was deemed to present an opportunity for conservation. This research focused upon opportunities arising from changes in land cover under the Global Sustainability scenario due to the focus of this scenario upon conservation and the preservation of biodiversity. It could be argued that pressures under a Regional Enterprise future (see Holman and Loveland, 2002; Munday et al. 2010), in particular those imparted by a rising population and upon food resources, might also lead to unexpected opportunities to create new wildlife habitats, arising from the cheap price of land taken out of agricultural production due to the removal of subsidies (Shackley and Deanwood, 2003). However, it is unlikely that these new areas would be afforded any long-term protection in terms of conservation policy or habitat designations which are required to sustain wader populations (Wilson et al. 2004). Consequently, new habitat created under a Regional Enterprise future would probably face pressure for reversion to agricultural production during periods of favourable market conditions, such as a sustained increase in the price of cereals (Parry et al. 2004). Nevertheless, the methodology we present is generic and could be applied to different scenarios as desired.

A further limitation was that the identification of habitats suitable for bittern involved the use of a set of criteria, of which some may be deemed subjective. Whilst evidence in the UK suggests that bittern prefer areas of reedbed comprising shallow water pools and scrub (Gilbert et al. 2005a), in other parts of Europe they appear much less selective of a particular habitat type. For example, some European studies suggest that bittern have a preference for a much more diverse habitat mix than found amongst UK populations including rushes, rice-fields and woodland-fringe (e.g. Adamo et al. 2004; Puglisi et al. 1997; Wretenberg et al. 2006). Consequently, the approach implemented here may require adaptation before it is applied within other non-UK based localities.

A final criticism might concern the prediction of breeding wader population sizes. In reality it is unlikely that each land parcel could wholly sustain the estimated populations. Evidence suggests that numbers are more likely to be maintained through immigration from other, more heavily managed (e.g. RSPB-owned), sites (Gilbert et al. 2007; Eglington, 2008a; Smart, 2005). This is particularly true for redshank as it is a species that historically has a smaller home-range size (Wilson et al. 2005) meaning that it is less likely to travel further in order to find suitable habitat. As a result, some of the more isolated sites identified as being potentially suitable may not be adopted by either wader species considered. Indeed, Gilbert et al. (2010) note that suitable sites for bittern were most likely to be closer to current core populations. However, the process of identifying current populations is likely to be difficult given the secretive nature of many breeding wader species and would inevitably require a more detailed audit of current breeding wader locations within Broadland.

It is hoped the outputs presented in this study could be of use to a variety of decision-makers, land managers and conservation bodies. We propose the mapped outputs could provide a range of potentially suitable sites that may be utilised to aid targeting of Environmental Stewardship options in response to future changes in land cover. Outputs may particularly be of use to individuals who are tasked with identifying areas of conservation potential that may warrant future protection. We suggest the results of the analysis highlight a considerable potential capacity to support breeding wader populations in the future.

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Chapter 5

Applying scenarios at local-scales: exploring the utility of downscaling to decision-makers in the Norfolk Broads (Broadland), UK

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Applying scenarios at local-scales: exploring the utility of downscaling to decision-makers in the Norfolk Broads (Broadland), UK

Abstract

There is benefit in linking local- and the global-scales through a process of downscaling by way of gaining greater understanding of future change across all levels of complexity. Scenarios are often utilised to compare a range of futures and a variety of datasets are available from scenario-based projects, including descriptive narratives and quantitative land cover data, that may provide useful insight into future landscape change. However, such outputs are often limited in their application to local areas by their coarse spatial resolution. Consequently, a number of downscaling methodologies, and downscaled scenario datasets (including land cover change data and maps depicting potential conservation opportunities), now exist. Despite the rise in downscaled outputs, there are a limited number of studies which investigate the usefulness of downscaled datasets to end-users. Therefore, this paper presents findings from a series of interviews which discuss the usefulness of some downscaled scenario outputs to decision-makers. A case study of the Norfolk Broads (Broadland), UK, an internationally and environmentally sensitive wetland landscape, is utilised. Findings indicate that downscaled outputs may provide a range of benefits to decision-makers, however, further validation and ground-truthing is required prior to use in engagement activities and/or decision-making processes. Evidence suggests that the process of downscaling, and the downscaled outputs presented, may go some way in stimulating debate about Broadland's future, a discussion which appears long overdue.

Keywords: scenario, downscaling, decision-making, land cover change, narratives

1. Introduction

Global-scale changes in climate, environment, economies, populations, governments and cultures are apparent at local-scales. Likewise, changes at a local-scale contribute to global changes as well as being affected by them. As a result, linking the local and the global-scales through a process of downscaling, defined as the reduction of time and/or space dimensions of coarser resolution data (Jacques, 2006), can potentially yield deeper understanding of future change across all levels of complexity (Wilbanks and Kates, 1999).

At the present time, a sizeable proportion of the literature has focused upon relating local places to global change from a top-down perspective, from the global to the local, using scenarios containing predictions of future changes in climate or socio-economic systems (e.g. land cover change) (Alcamo et al. 2006; Dockerty et al. 2005; Environmental Protection Agency, 2009; Sanstad et al. 2009). Such scenarios have typically been downscaled from coarser-scale models using a Geographic Information System (GIS). For example, the ACCELERATES project (Abildtrup et al. 2006) utilised a GIS framework and a process of downscaling to produce 500 m grid squares of European land cover change using global-scale climatic and socio-economic scenarios (IPCC, 2000) for the years 2020 and 2050. There has been a growing interest, however, in considering the effectiveness of this type of approach from a bottom-up perspective, asking questions as to the added value that downscaling may bring, the utility of downscaled scenarios to end-users and the ways by which downscaled scenarios might be improved (Wilbanks and Kates, 1999; Nicholson-Cole, 2005).

Scenarios are often utilised by decision-makers as a tool for exploring future changes as they can help elicit important information about how sensitive landscapes (e.g. wetlands – Nicholls, 2004), species (e.g. waders – Smart, 2005) or habitats (e.g. lowland wet grasslands – Olesen and Bindi, 2002) may react given changes driven by economic development, environmental change or societal values. They are often described using qualitative (e.g. storylines or narratives) and/or quantitative datasets (e.g. land cover data) and may be developed using stakeholder and expert consultations (e.g. Shackley and Deanwood, 2003) or using mathematical models (e.g. IPCC, 2000).

In recent times, both qualitative and quantitative scenario outputs from global-, national- and regional-scale scenario-based projects, including Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005), UKCIP (Hulme and Jenkins, 1998; Hulme et al. 2002), RegIS (Regional Climate Impact Studies in East Anglia and North West England – Holman and Loveland, 2002) and REGIS2 (Holman et al. 2004) have become increasingly available and of interest to decision-makers, particularly those investigating future landscape change. As data availability has grown, procedures for downscaling scenario outputs have also become more available (van Vuuren et al. 2010 provides a useful summary) which may improve the relevance and applicability of national- or regional-scale datasets to local landscapes, and hence their legitimacy to decision-makers and planners. Consequently, a number of downscaled scenario outputs now exist including maps which depict future land cover change driven by changes in agricultural policy, the economy and population (Munday et al. 2010; Kok et al. 2006; Dale et al. 1993) and land parcels that represent conservation opportunities for particular species (Chapter 4) or management alternatives (Lathrop and Bognar, 1998).

There are numerous potential benefits to decision-makers associated with downscaled scenario outputs as they provide local relevance to regional, national, or even global predictions. Perhaps of most interest include their ability to provide input into localised studies of habitat fragmentation and connectivity (e.g. Southern et al. 2006; Theobald et al. 2000), adaptation and mitigation of CO_2 emissions (e.g. Harvey, 1993) and for investigating the response of local landscapes to changing policy (e.g. Dockerty et al. 2006). In addition, downscaled scenarios may assist with the production of computer visualisations to engage individuals with the localised impacts of future climatic and socio-economic change (e.g. Appleton and Lovett, 2003; Nicholson-Cole, 2005; Sheppard, 2005).

Nevertheless, there are caveats. Indeed, many of the uncertainties inherent in global-scale datasets used for downscaling may become exaggerated at local-scales and the validity of assumptions underpinning mathematical models may further be questioned at fine spatial resolutions, particularly as local constraints are often difficult to take into account. For example, the influence of policies, particularly those associated with agriculture, in driving landscape changes at local-scales, is suggested as being a key element that introduces uncertainties (Rounsevell et al. 2006). A further limitation is that the implied accuracy of mapped outputs may mislead or make it difficult for individuals to envisage the full range of possible futures available to them (Nicholson-Cole, 2005). Sheppard (2001) suggests that the increased sophistication of outputs depicting potential futures driven by climatic and socio-economic changes can mask uncertainties associated with scenarios, and that the level of complexity presented, alongside the data-driven nature of outputs, may unintentionally force users to not think beyond the futures that they are presented with.

Despite the improved availability of relevant data and capacity of downscaling methodologies to generate localised outputs, there are few studies which have examined the usefulness of downscaled outputs to their intended end-users. Such an understanding is important given that local decision-makers typically have valuable experience of working with scenarios in varying contexts and planning for future changes, incorporating perspectives of both macro- (e.g. national-scale policy) and micro-scale drivers (e.g. local landowners). They are hence well-placed to comment on how downscaled map outputs might be utilised and where any pitfalls might lie. We suggest that eliciting opinions on the value of downscaled scenarios amongst these groups thus facilitates an assessment of the effectiveness of downscaling methodologies to deliver useful outputs.

An area where it is suggested that downscaled scenarios might be particularly useful to decision-makers is in the investigation of landscape change, particularly within sensitive environments such as wetlands. An example of such a locality is the Norfolk Broads (Broadland), East Anglia, UK, an internationally important wetland landscape that has experienced substantial changes throughout its history (Moss, 2001; Broads Authority, 2007). Both pressures and opportunities (e.g. changing agricultural policy, climate change, and economic support measures) imparted due to changes in social, economic and environmental systems are likely to influence the Broadland landscape, including its species and habitats, in the future. As a result of its complex management, environmental sensitivity and competition for land cover, the need to identify how these changes may result in modifications to the landscape is a pressing issue for decision-makers. Consequently, the need for a more adaptive management style which reacts to changing future conditions has been highlighted (Folke et al. 2003; Sutherland et al. 2004).

As a response to the issues described, the Broads Authority (the Special Statutory Authority managing the Broads) has instigated a 20-year 'visioning' exercise. As part of this project, the impacts of future climatic and socio-economic change upon Broadland are being investigated over a 100 year time-scale (see Broads Authority, 2007, p.21-26). In addition, further work by the authority has focussed upon the identification of land parcels which may present future opportunities for conservation (Broads Authority, 2004), termed Wetland Enhancement Areas, with particular emphasis placed upon wading bird species. Consultations with local experts and stakeholders, coupled with flood model data, were utilised to delineate suitable land parcels that may represent conservation opportunities.

Whilst the authority is clearly considering the likely impacts of future changes upon Broadland as part of its remit to protect, manage and enhance the Broad's sensitive landscape and its species, there are some problems with the approaches it has adopted. Firstly, there is limited consideration of changes likely to be witnessed on-the-ground, particularly with regard to the importance of local-scale drivers (e.g. agriculture or land cover change) in facilitating change. Secondly, the delineation of land parcels representing potential opportunities for conservation has failed to take into account opportunities arising from changes in land cover. Consequently, a set of downscaled scenarios, comprising maps depicting future land cover change and conservation opportunities were produced to help with choices about management of the Broadland landscape over the next century (Munday et al. 2010).

The research described here seeks to investigate the usefulness of scenario outputs, using a case-study of maps depicting future land cover change (Munday et al. 2010) and conservation opportunities for waders (Chapter 4), amongst decision-makers working within Broadland. Findings from a series of interviews are presented in relation to four topics of discussion; (i) establishing familiarity with scenarios and current level of use; (ii) comparing interpretations of regional-scale and downscaled scenario outputs; (iii) identifying benefits and limitations, and; (iv) examining the potential role of downscaled outputs in local decision-making processes.

2. Methodology

2.1. Study area

The study area covers approximately 95,000 ha of the Norfolk Broads (Broadland), UK (Figure 5.1). The Norfolk Broads (Broadland) forms one of the largest networks of wetlands in the UK, and is unique in Europe in terms of its ecology and landscape (Moss, 2001). The Broadland landscape comprises a mosaic of shallow lakes (broads) and rivers, grazing marshes, fen and woodland, as well as intensive arable lands that support numerous threatened and scarce species of flora and fauna of high conservation concern. There are over 7,000 ha of designated areas containing 28 Special Sites of Scientific Interest (SSSIs), seven National Nature Reserves (NNRs) and nine Local Nature Reserves (LNRs), seven Ramsar sites and four Special Areas of Conservation (SACs). There is good scientific understanding of Broadland's ecology (Ditlhogo et al. 1992; Cowie et al. 1992). Yet in recent times, increasing pressures from tourism and recreation, climate change and changing agricultural policy mean that the landscape is coming under pressure. These pressures coupled with the environmental sensitivity of the locality mean that decision-makers are under increasing pressures to make important choices today, for example, on the re-creation, protection or loss of habitats such as grazing marsh, despite uncertainties regarding the future impacts that these decisions might have upon Broadland's species and users.

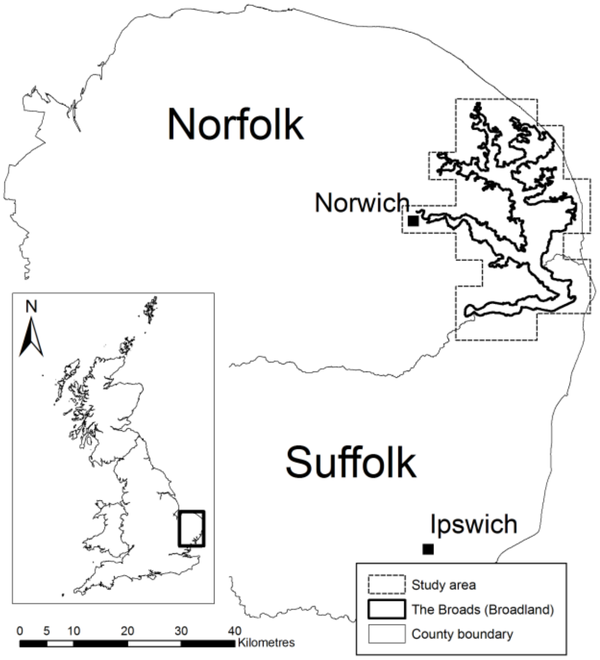

Figure 5.1. The Broadland study area. © Crown Copyright. All rights reserved. Ordnance Survey 2010.

2.2. Interviews

Meetings were arranged with representatives from a number of governmental and non-governmental organisations. These comprised the Broads Authority, Natural England, the Norfolk Wildlife Trust and The Royal Society for the Protection of Birds (RSPB). These particular organisations were selected because of their influence upon Broadland's landscape, including its species and habitats, in terms of its protection and enhancement, and future development. The Broads Authority and Natural England play important roles in making decisions about the long-term future of Broadland via policy formulation and delivery. The Broads Authority, in particular, is tasked with conserving and enhancing the natural beauty of the Broads alongside promoting their use through tourism and for balancing the interests of its many users. Natural England works using an overarching framework, in terms of policy development and implementation, which aims to protect and improve the wider natural environment. The Norfolk Wildlife Trust and the RSPB were selected for their expertise in the conservation and protection of Broadland's species and their habitats. The RSPB is responsible for managing, maintaining and enhancing site designations and for promoting conservation of birds. The Norfolk Wildlife Trust is a registered charity which aims to restore, recreate and reconnect habitats, particularly those of conservation concern.

A total of five participants were identified for interview consisting of a senior policymaker, a landscape architect and a conservation manager. In addition, two conservation officers were also recruited as their role involves working at both local- and national-scales, particularly with regard to on-the-ground policy delivery. The conservation manager was selected due to their expertise working with UK nature conservation policy, for example UK Biodiversity Action Plan (hereafter UKBAP) and Local Action Plan (hereafter LBAP) (see UK Biodiversity Group, 1999; Broads Authority, 2009), and evaluating and monitoring locally designated areas. The senior policymaker was enlisted to provide insight into future policy development and to offer advice as to the feasible application and practical use of the downscaled scenario outputs at a regional level. Finally, the landscape architect was selected to provide specific expertise on landscape benefits arising from land cover changes depicted by the scenarios. All of the participants had substantial experience working within Broadland. Potential respondents were identified through email or telephone enquiries to the relevant department of the organisation in question.

Interviews were undertaken between June and July 2010. Initially, participants were given an introduction to the purpose of the research and asked to introduce themselves, their area of expertise and experience working within Broadland. The sessions then took the form of semi-structured discussions centred on four topics, or themes, whereby respondents were prompted to contribute views and experiences. Table 5.1 provides a summary of the topic guide which was used to lead discussions.

Discussion topics	Issues covered
Establishing familiarity with scenarios and level of use	- Defining the word 'scenario' - Establishing the level of use of scenarios - Describing how scenarios are currently used (if at all) - Identifying areas where utilising scenarios might be beneficial
Comparing interpretations of outputs	- Gathering interpretations of scenario narratives from two scenarios (Global Sustainability and Regional Enterprise) - Discussing interpretations using downscaled land cover maps - Establishing the feasibility of the scenarios - Discussing the ways in which the land cover maps helped interpret the scenario narratives
Identifying benefits and limitations	- Identifying additional information that might help decision-makers interpret the scenario narratives - Evaluating the benefits and limitations of the downscaled land cover maps - Establishing the usefulness of the downscaled land cover maps in their current form
Examining role of downscaled outputs in decision-making	- Discussing the role of downscaled mapped outputs (land cover maps and conservation opportunity maps) in helping decision-makers make decisions about the landscape

Table 5.1. List of discussion topics, questions and scenario narratives held by the interviewer, to be used in each session.

Firstly, participants were asked to explain their interpretation of the word 'scenario' and to provide views and/or experiences on how they utilised scenarios in their work. This topic was primarily employed to ascertain the level of experience that each decision-maker had with scenarios and to determine whether greater familiarity with scenarios helped participants envisage a more diverse range of impacts.

Secondly, participants were asked to describe the likely impacts of future changes upon the Broadland landscape using coarser-resolution scenario narratives and downscaled land cover maps. This topic was designed to determine whether the spatial resolution of the scenario outputs might influence the range of impacts that participants were able to envisage. To facilitate this procedure, narratives, in the form of textual descriptions, from two opposing scenarios (Global Sustainability and Regional Enterprise which focussed upon conservation and economic development respectively – see Holman and Loveland, 2002) were presented and participants were asked how they thought the landscape might appear, or how the changes described might manifest, in the future given changes implied by the narratives. Two opposing scenarios were utilised in this process to help determine whether the focus of the scenario influenced the range of interpretations that were envisaged. The two scenario narratives presented to participants were as follows:

> *Economic growth is controlled so that fragile ecosystems are protected….high priority is assigned to the protection of habitats. Changing agricultural support measures to farmers and increased flood risk has caused a land use change from arable to permanent grassland. People move away from large urban areas and seek out a higher quality of life in the countryside.* (Narrative one – Global Sustainability scenario)

> *Economic growth is high leading to pressures upon food and water resources. Agricultural support moves away from sustainable production. Nature conservation policy is not sufficiently strong to restrict development pressures on the natural environment. People move closer to larger urban centres.* (Narrative two – Regional Enterprise scenario)

Each of the land cover maps was then revealed and the question repeated. Participants were then prompted to comment upon the extent to which seeing the corresponding land cover map(s) had changed their views or opinions from just seeing the narrative.

The third discussion topic focussed upon identifying the benefits and limitations of the downscaled land cover maps, and more generally, the downscaling methodology adopted in the wider research project. Comments were also gathered on the feasibility of trends depicted by the narratives and land cover maps, and also the likelihood of the scenarios occurring within Broadland. Participants were then asked to consider any additional information that might have helped them interpret the narrative and any issues that may limit the usefulness of the outputs. The next stage of the methodology which was incorporated to establish the strengths and weaknesses of the downscaled land cover maps. It was hoped that insight gained through this process would be able to feedback into future downscaling studies and improve the applicability of downscaled outputs to decision-makers. Finally, the potential role of downscaled scenario outputs (including both the land cover and conservation opportunity maps) as a decision-making tool were explored. This final topic helped to ascertain the use of the downscaled scenario outputs in their current form and allowed participants to comment more generally upon their potential application.

Interviews lasted an average of approximately one hour and were recorded; additional notes were also taken to capture any points of particular interest. Audio recordings and notes were then transcribed into a summary for each interview (although not transcribed verbatim). To maintain anonymity, individual(s) are referred to by their role where quotations are cited in the text.

2.2. Downscaled scenarios maps used in interviews

The downscaled information presented to participants in the second stage of interviews comprise land cover maps described in Munday et al. (2010) along with conservation opportunity maps derived in Chapter 4. We refer readers to the original manuscripts for full descriptions of datasets and the downscaling methodology, and give brief descriptions here.

The land cover maps were developed using gridded land use data (comprising 40 five kilometre grid squares) from a regional-scale scenario based project (RegIS - Holman and Loveland, 2002). Two time-points were utilised; 1995 (the baseline – that used by RegIS) and the year 2100. Maps were modelled in a GIS (IDRISI Andes v15.01 – Eastman et al. 1993) and incorporated eight land cover categories: arable, permanent grassland, recreation, roads, uncultivated land, urban, water and woodland. Two scenarios were included as they considered both climatic and socio-economic changes; Regional Enterprise and Global Sustainability (related to the UKCIP National Enterprise and Global Sustainability scenarios, respectively – see UKCIP, 2001). The Regional Enterprise scenario represents a world in which the economy takes precedence over natural systems. In the Global Sustainability scenario, conservation of biodiversity is paramount and economic growth is afforded less importance than environmental sustainability (for comprehensive storylines and narratives see UKCIP, 2001; RegIS, 2002 and Shackley and Deanwood, 2003). Changes due to climate were derived from 1998 UKCIP HIGH (linked with Regional Enterprise scenario) and LOW (linked with Global Sustainability scenario) climate scenarios, respectively (see UKCIP, 2001; Hulme and Jenkins, 1998).

The conservation opportunity maps used in the interview comprised land parcels suitable for two breeding wader species, redshank (*Tringa tetanus*) and bittern (*Botaurus stellaris*), delineated using the land cover maps previously described. These species were selected due to their decline in number and distribution across the UK over the last 25 years (BirdLife International, 2004). In addition, the bittern is listed as 'priority concern' in the LBAP for neutral grasslands (Broads Authority, 2009) whilst the redshank population declines are of particular concern (Wilson et al. 2004).

Suitable land parcels for the waders were defined as those which underwent a transition from arable to permanent grassland between the two scenario time-points, and were within the flood zone (i.e. those parcels most likely to be wet and to transition away from agriculture). Results suggested that these arable areas tended to be located upon flood prone, low agricultural grade land. In addition, two land management scenarios (one for each wader, termed 'moderate' for redshank and 'maximum' for bittern) were also envisaged comprising contrasting management prescriptions available to farmers under the Environmental Stewardship payment scheme. For redshank, these prescriptions included re-wetting of permanent grassland and reduced livestock densities whilst those for bittern involved the creation of reedbed via inundation.

Figures 5.2 to 5.5 provide examples of the maps presented to participants. Figure 5.2 depicts the baseline land cover map whilst Figures 5.3 and 5.4 represent the two scenarios (Global Sustainability and Regional Enterprise, respectively). Finally, Figure 5.5 depicts opportunities for conservation under two land management scenarios for redshank and bittern.

FIGURE 5.2 HERE

FIGURE 5.3 HERE

FIGURE 5.4 HERE

FIGURE 5.5 HERE

3. Results

Salient points within each of the four discussion topics are presented in the following four sections which are ordered according to the topic guide.

3.1. Establishing familiarity with scenarios and their level of use

Interpretations of the word ‘scenario’ were strikingly similar amongst all participants suggesting some degree of exposure to scenarios or scenario-based projects. The general feeling was that scenarios represented one of a number of possible options of the future based upon changes in specific parameters, particularly policy.

> *A scenario is a potential or possible option…probably with a final outcome presented.* (Conservation Manager)

> *There are many scenarios for the Broads, it depends on what courses of action, what policies, are pursued and what resources are provided in the future.* (Senior Policymaker)

There was less agreement in terms of the timescales most useful to them. Comments suggested that short- (up to 5 years) to medium-timescales (5 to 20 years) were more highly valued amongst individuals whose work was heavily influenced by policy. For example, participants from conservation organisations noted that the European Union Birds and Habitats Directives and the UK Biodiversity Action Plan (UK Biodiversity Action Group, 1999) played a pivotal role in their work and they were therefore likely to find these sorts of timescales more comfortable to deal with. Those from the Broads Authority cited longer-timescales (20 years or more) as being more important in the context of their work and it was also suggested that policymakers might start to place greater emphasis upon the importance of longer timescales in land management and planning policies.

Only one participant had first-hand experience working with scenarios in the same context as that adopted in this research (i.e. those which incorporated long-term predictions of future climatic and socio-economic changes), yet there was general consensus concerning the overall benefits that utilising scenarios may bring:

> *I see them [scenarios] most usefully as a way of helping us develop our own thoughts about where policies/decision-making may change.* (Conservation Officer)

> *It's about getting people to acknowledge that the Broads has always changed and will continue to change.* (Conservation Officer)

Several participants suggested that employing scenarios might be beneficial for prioritising workloads. An example was given of identifying mill structures most likely to be susceptible to future flooding and prioritising repairs. Other comments highlighted their potential for use in public engagement activities. However, it was noted that in light of recent adverse reactions within some Norfolk villages to possible future options for flood protection (see BBC, 2008), it may be necessary to refrain from presenting any 'extreme' changes to the public or from using recognisable locations.

> *Scenarios are interesting to get the debate going, but they're very difficult to manage in relation to the public.* (Landscape Architect)

Despite the limited use of scenarios by the majority of participants, there was clear agreement that a debate about the future of the Broads was pressing and scenarios should play a key role in this process. It was also recognised that a mechanism for engaging local people with a range of different futures is currently required to aid future management decisions.

> *I do think there's still the need to have a debate about the Broads, and in having that debate we should be looking at scenarios…I think it's [the debate] for a wider grouping of interests and sectors…if anything, we need to be unifying behind some long-term vision.* (Senior Policymaker)

3.2. Comparing interpretations of regional-scale and downscaled outputs

Interpretations utilising regional-scale narratives and those using localised land cover maps were diverse. In general, using the scenario narratives, participants were able to provide a high level of detail when describing the likely impacts of the two scenarios upon Broadland and this provoked a large number of comments, albeit with a wide range of interpretations. Participants were able to draw upon previous experience and knowledge of the landscape to form opinions and to provide insight into how changes prescribed by the narratives might manifest into landscape changes witnessed on-the-ground. For example:

> *If you think about areas like Loddon bridge, towards Wroxham, you then look over the valley and you've got definitely got arable, and then coming down to some grassland, the river, and the floodplain…you're going to see the riverine grassland changing to reedbed or fen…it's*

> *those high points in the Broads, like that bridge, where I think you'd see quite a difference in [the] landscape.* (Conservation Officer describing some of potential landscape changes under the Global Sustainability scenario)

Under the Global Sustainability scenario, participants tended to envisage a positive impact upon the Broadland landscape with widespread reversion of arable land to permanent grassland within the flood plain resulting in the re-creation of reedbed and fen (where soils and hydrological conditions allowed) and improved connectivity of habitats. For example:

> *…changing agricultural support measures to farmers, that's obviously a huge thing because there are areas in the Broads where we would like to see a change, particularly in the flood plain, to more grassland…seeing the really low wet areas changing to fen and reedbed, but there's not enough of a financial incentive for that to happen and it would be brilliant if we could see much more join-up [of habitats]*. (Conservation Officer describing some potential landscape change under the Global Sustainability scenario)

Interpretations of landscape change using the Regional Enterprise narrative tended to focus upon increasing habitat fragmentation and incidence of flooding, degraded wetlands and widespread arable reversion:

> *Impacts would be…intensification of agriculture, people would want to see continued or higher standards of flood protection, and the change in climate would require increasing investment…ultimately the cropping would have to justify that level of expenditure…in some ways its counter the vision of the Broads…I would say it's not just about fragmentation of habitats, it's whether the wetlands are sustainable*. (Senior Policymaker describing some potential landscape changes under the Regional Enterprise scenario)

> *Well needless to say, that [the scenario] would have a detrimental impact on Broadland…agricultural support moving away from sustainable production…this would probably be the 'doomsday' scenario out of the two, I can't see any positives as the Broads are concerned from a biodiversity point of view*. (Conservation Manager describing their thoughts on the future under the Regional Enterprise scenario)

Interpretations using the land cover maps, on the other hand, tended to be quite similar and comments typically focused upon specific locations where participants witnessed unexpected changes or that raised further questions regarding management of the land cover change. For example, several participants focussed upon specific areas of permanent grassland near Berney marshes (located approximately 15 miles south-east of Norwich) that had transitioned from arable in the baseline land cover map. In this situation, it was suggested that this particular change in land cover was likely to occur, given current restructuring of agricultural subsidy payments and improbable provisioning of future flood protection in the area, but this might not always be the case for other areas. Some participants therefore suggested that interpreting the scenario narratives, in conjunction with the land cover maps, was more difficult in particular localities. Hence, a combination of both the narratives and land cover maps was preferred:

> *What the narrative tells you that this [the land cover map] doesn't... [with regard to pressures upon water resources]…that's not just quantity, that's quality…[the land cover map] is very much about area, about scale, whereas what you get from the narrative is more of the detail…you certainly need both.* (Conservation Officer)

In some locations (such as Upton/South Walsham, located approximately 10 miles east of Norwich), participants highlighted the importance of micro-scale drivers (e.g. individual land owners) in facilitating different landscape changes. Comments indicated that the rate of change depicted by the land cover maps was therefore likely to be extremely variable in some localities. For example:

> *I think when you start going down to this level of detail, that's when you start running the risk of thinking, well actually the policy in this small area might be significantly different from that small area because of land ownership or someone wants to do something differently from current drivers.* (Conservation Manager)

It was also argued that conservation organisations might identify and prioritise areas of land for investment or modification which would negate any wider landscape changes; these sorts of choices made interpreting the narratives in combination with the land cover maps sometimes problematic:

> *Whilst we would say the Broads overall is a priority, within that there are even hotter spots.* (Senior Policymaker)

Other participants commented upon some of the broader-scale changes depicted by the maps which they were unable to envisage using just the narratives. For example, under the Global Sustainability scenario, changes seen within the floodplain comprised an increase in permanent grassland which occurred almost entirely within the Broads Authority Executive Area (the authority's administrative boundary which was delineated to encompass the floodplain whilst avoiding major settlements). Comments suggested that participants were surprised at the limited extent of land cover changes that manifest outside of this boundary (essentially representative of the floodplain) and that this was not something they had considered through interpreting the scenario narratives on their own.

3.3. Identifying benefits and limitations

In general, the majority of participants found the land cover maps to be useful and to provide added value over just using scenario narratives. Comments tended to focus upon the capacity of the maps to reinforce changes prescribed by the narratives in a visual format, particular spatial extent:

> *I find maps really useful because I think I'm a very visual person…so seeing the map actually makes you think about the scale of it.* (Conservation Officer)

> *By looking at the narratives I can actually picture what that means in the Broads, I think seeing it in a mapped form starts to help you think about how widespread or fundamental the change might be.* (Senior Policymaker)

Nevertheless, there were also a number of limitations identified by participants. One particular example was a concern centred on the flexibility of scenarios depicted by the land cover maps. For example, a participant proposed a future for Broadland that comprised a strong element of agricultural production (i.e. similar to that under a Regional Enterprise future) but with limited funds available via Government flood defence budgets (i.e. similar to that under a Global Sustainability future). A further concern centred upon the lack of consideration of extreme events within the scenarios.

> *There's lots of talk about visioning the future of the Broads…I think it's important to depict it and show people what the potential futures are, I just worry the scenarios presented are one dimensional…you could have a scenario which is [focused upon] agricultural production, but the Government have no money to put into flood defence…so it's down to the individual, it's up to individual land owners…it's a bit more of a mix of things [drivers] then*. (Conservation Manager describing an alternative future for Broadland)

> *Some unexplained factors could cause some big unexpected change that hasn't been included in the scenario*. (Conservation Officer)

Some concerns were also raised regarding the plausibility of the scenarios themselves. A few comments were made which concentrated upon the feasibility of extensive arable reversion under Regional Enterprise scenario, and the inherent practicalities of undertaking such drastic changes in land cover. For example, providing adequate flood protection and also maintaining water levels were popular arguments.

> *To manage this scenario [Regional Enterprise] would demand all sorts of structures in rivers, around compartments, that would have a profound effect on other sectors…recreation, for example boating, the natural floodplain would be fundamentally changed…so I think this is where the [land cover] maps are in error because doing this in one place would have a profound effect elsewhere*.

(Senior Policymaker)

Further limitations focussed upon the problems inherent in developing highly spatially detailed maps representing future changes, in particular those associated with issues of accuracy implied by map outputs and the potential problems of utilising these outputs in events that aimed to engage local people or other stakeholders. The general feeling was summarised by the comments below:

> *I think they're [the land cover maps] too complex, I don't think they pull out the message that you're trying to give over…sometimes people cannot have the imagination to think any deeper than the maps, lots of people can, but there's some people out there who can't.* (Landscape Architect)

> *It's a double-edged sword really…you've got the reality of being able to see the changes, this is what it could look like in the future, but then that's obviously someone's land, or where someone walks. You need to be able to do the high-scale and the low-scale, and that's what you need if you're working at a policy level in an area, you need to be able to work at the high-scale and actually to be able to think about what that means on-the-ground.* (Conservation Officer)

Many comments were made by participants which centred upon the identification of specific features or landscape changes. Indeed, one of the more common procedures was for participants to locate their own homes and to comment upon the projected land cover changes in the surrounding area. Several participants discussed the possibility of providing land cover maps depicting a generic landscape that individuals were unable to personally identify with. On the other hand, others argued that this type of ‘watering down’ sidestepped the wider issue of promoting discussion about future climate and socio-economic change within Broadland and that a catalyst was needed to spark debate.

Participants also highlighted additional information that may improve the usefulness of downscaled land cover maps to them. It was widely agreed that information on percentage gain/loss of each land cover type between the two scenario time-points would be helpful, coupled with additional justification of the scenario in a policy context. Whilst participants generally agreed that they were able to link land cover changes seen within the maps to changes described by the narratives, it would be advantageous to more explicitly state policies driving some of the more contentious changes and winners or losers next to the maps:

> *Knowing the extent of the whole area, amounts of habitats, is potentially quite useful…knowing how much would be lost or gained*. (Conservation Officer 1)
>
> *For me it would be nice to have the policy context, so you say in the Regional Enterprise scenario…the budget for flood and coastal defence would need to be raised by ‘x’ percentage…it’s about the positives as well as the negatives because whichever scenario you come from, some things are going to be winners and other things are going to be losers…it’s about being as up front about the where the winners and losers are, I think you do it in words [the narratives], you could just do it better in the maps*. (Senior Policymaker)

Other suggestions were directed towards displaying additional high spatial resolution case study sites along with the land cover maps so that users were able to distinguish both broader- and local-scale changes. This was perhaps surprising in light of earlier concerns regarding the identification of recognisable landscapes within Broadland. Additional remarks focussed upon adding a level of sophistication to the maps, for example by developing computer generated 3D landscape visualisations. However, the extra resources and expertise needed to generate such images were identified as potential barriers to achieving this.

3.4. Examining the role of downscaled outputs in decision-making

It was widely agreed that downscaling provided an extra level of detail not offered by traditional coarser-scaled scenario outputs and that the downscaled maps were useful to participants, particularly when used in conjunction with scenario narratives. Several participants stated that they could see a potential use for the downscaled land cover maps in public engagement activities and for use by local planners looking to prioritise land parcels for conservation or development.

> *I think it's critical in engagement, and actually very critical in thinking about what we want the Broads to deliver in the next 50 to 100 years.* (Senior Policymaker)

> *I think they're really useful, not with this level of complexity, but in terms of looking at habitats across the Broads to give you a sense of scale of what's there and where opportunities are because you have to look at ecosystems as a whole…having this scale of information is really important.* (Conservation Officer)

There were further comments which focussed upon the potential of incorporating land cover and conservation opportunity maps into a Broadland assessment of habitat suitability for a range of important species. There was agreement that the conservation opportunity maps were potentially very useful, specifically to facilitate the identification of suitable land parcels for breeding waders in Broadland. Participants agreed that the value of the conservation opportunity maps was primarily that of identifying large blocks of land that may provide suitable habitat. Other comments focussed more generally upon utilising both land cover and conservation opportunity maps to provide information at different spatial scales; this was particularly important to decision-makers given the scientific grounding of the downscaled scenario outputs.

> *I think they [conservation opportunity maps] are very useful…in terms of looking at habitats across the Broads to give you that scale of what's there and where opportunities are.* (Conservation Manager)

> *You could target certain areas, using other datasets such as various bird surveys, so you can actually target areas that are important for a particular bird or [for] nature conservation that aren't being targeted at the moment.* (Conservation Officer)

From the amount of discussion generated it seems that participants recognised the benefits that downscaling, and downscaled outputs, might bring to decision-making. However, there was agreement that further work, in terms of validation and ground-truthing, was needed in order to make downscaled outputs more valuable to decision-makers.

> *For me, in the work that I do, these kinds of maps would be integral, but it would then be taking it on to the next level of downscaling, which would obviously be the ground-truthing…it's an integral part of the process [the process of downscaling] but it wouldn't be the final part of the process.* (Conservation Officer)

There was also agreement that ground-truthing and validation should be part of a wider process which also takes into consideration issues of scale and the views of local people. Indeed, several participants commented that these types of 'futures' works were being planned but there was still debate regarding the format of discussions:

> *The sense is generally resistance to change, and the difficulty with climate change is that change is inevitable…this is the conundrum we're in*. (Senior Policymaker)

> *We do need a tool like this, we do need something to start opening up the debate with local communities…trying to show that the landscape is dynamic by putting it into perspective about how the landscape has changed over the last two millennia…people can say 'well that's changed a lot in a short space of time', we can then say 'well what's going to happen in the future?'…let's have a think about what the scenarios are, it's about trying to open up that debate*. (Landscape Architect)

4. Discussion and conclusions

This study has investigated the usefulness of downscaled scenario outputs to decision-makers. Using semi-structured interviews with five participants from conservation bodies and non-governmental organisations, views and opinions were elicited and presented in relation to four topics of discussion.

A key contribution was seen to be the ability of downscaled scenarios to provide an extra level of detail that was not provided by traditional coarser-resolution datasets. In addition, the downscaled scenarios served to reinforce the potential scale of landscape change within Broadland and helped to elicit questions regarding the plausibility and practicality of implementing some wider landscape changes. An example which received particular attention was the widespread transition to arable land under the Regional Enterprise scenario. In this case, participants were only able to envisage the possible spatial extent of land cover change being described by the narrative when they were presented with downscaled maps. A response to this was for participants to comment more generally upon the plausibility of facilitating the land cover change in question, suggesting that textual narratives may be less likely to be questioned than mapped outputs. This reinforces our belief that downscaled outputs can help stimulate debate about changes being depicted.

Issues of scale, both in spatial and temporal contexts, emerged as an important theme and presented both an opportunity and a limitation of usefulness. There was a modest preference towards incorporating more constrained timescales within downscaled outputs, comprising future projections of up to 20 years. Such preferences are perhaps unsurprising given the typically short lifespan (5 to 10 years) of many environmental policies (Dockerty et al. 2006). At the same time, realisation of the potential benefits of incorporating longer timescales in land management and planning policies (see Haeuber, 1996) indicated the potential importance that considering longer timescales might bring. Whilst presenting decision-makers with longer timescales is not without difficulties in downscaling studies (for example envisaging distant impacts upon landscapes have been noted as an inherent problem - Nicholson-Cole, 2005) findings in this research suggest that using longer timescales may be particularly beneficial to help decision-makers consider futures beyond the realm of current policy.

A number of limitations associated with the use of the scenarios were developed. One of the key themes emerging from the interviews related to the inability of the downscaled scenarios as presented to encapsulate a wide range of viewpoints and inherently to provide a diverse range of possible futures. The problems of providing decision-makers with a limited number of scenarios (in the case presented here just two opposing scenarios were provided which were designed to cover a wide range of intermediate futures – Holman and Loveland, 2002) have been highlighted by other researchers (Sheppard, 2005), although it has also been suggested that providing a wider choice-set is also inherently problematic (Nicholson-Cole, 2005). Indeed the complexity of climate change and associated policy options (Keeney and McDaniels, 2003) means that providing participants with a large number of scenarios may cause confusion over the contingencies, associated risks and resultant choices that are available (Sheppard, 2005). The fact that providing many scenarios is inherently resource intensive is also a recognised limitation of downscaling methodologies (Pitcher, 2009; Rounsevell et al. 2006). This manifested here in the fact that the underlying land cover model required 360 individual runs, each needing approximately four hours run-time.

An additional limitation relates to the potential inflexibility of downscaled scenario outputs to incorporate further modifications. Given the complex nature of downscaling and the use of regional-scale land cover data, incorporating additional changes, for example substantial shifts in agricultural policy or more extreme changes in climate, may be difficult to retrofit. As a result, any significant modifications to the land cover maps might require further consultation exercises with local experts and stakeholders to pinpoint areas which experience future changes and to examine the robustness of scenario drivers to any changes that are envisaged; a process that is potentially time-consuming and necessitates expert knowledge and skills in the use of GIS (Shackley and Deanwood, 2003; Southern et al. 2006). In addition, it is likely that any elaboration of the scenario narratives via consultation exercises would be dependent on the skills of the individuals involved, the range of participants involved in the process and the quality of interaction that took place between them (Shackley and Deanwood, 2003) and may hence still fail to meet the demands of all end-users.

Nicholson-Cole (2005) and Sheppard (2005), cite difficulties associated with providing recognisable local images to individuals who are familiar with the landscapes being depicted. For example, it has been suggested that the realistic representation of landscape changes may imply that these futures are the only options available when the futures themselves may actually be part of a wider choice-set (Nicholson-Cole, 2005). This may be particularly problematic if the intention were to present maps to members of the public via consultation exercises (Sheppard, 2005). Consequently, undertaking modifications, such as the removal of iconic local landscape features like particular woodlands or roads, may help keep debate open if the land cover maps may be utilised in consultations with members of the public.

Despite the potential difficulties discussed, we believe that the costs associated with developing entirely ‘new’ scenarios would outweigh those associated with modifying the scenarios generated here. A number of recommendations thus emerge that might improve the usefulness of downscaled scenarios. At a basic level, these comprise the incorporation of contextual information alongside mapped outputs, including tables providing quantifications of land cover changes, and qualitative narratives that drive changes should be depicted. More involved recommendations focus upon utilising additional consultation exercises with local stakeholders and experts to further refine the outputs; an approach endorsed by other researchers (e.g. Berkhout et al. 2002; Shackley and Deanwood, 2003). Consultations could be utilised to incorporate a greater range of views and opinions in order to improve the relevance of outputs to users.

We believe a key potential use for the downscaled outputs might lie in participatory-GIS. Participatory-GIS involve the engagement of individuals in decision-making processes and typically consist of web-based surveys or interactive media such as video or context-sensitive images (i.e. whereby the user is able to select parts of an image that interests them and receives further information) (Pettit et al. 2006). A particular strength of participatory-GIS is in its ability to incorporate map-based outputs like those generated here and to empower users by involving them in decision-making processes (McCall, 2003). It is possible that the maps generated could be made interactive by being presented alongside a range of selectable options (i.e. narratives) where a resultant landscape change could be visualised. Users would receive instant feedback on their actions and benefit from being able to visually identify the possible impacts that their choices might have upon the landscape. In sensitive landscapes like Broadland, where small changes may have the greatest impacts, these are particularly important qualities.

It is hoped that the research presented here may go some way in contributing to forthcoming studies which consider Broadland's range of possible futures or simply as a mechanism that stimulates debate; a debate which, in light of climatic and socio-economic pressures facing Broadland, appears long overdue.

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Chapter 6

Conclusions

1. Conclusions

The research presented in this thesis has developed and implemented a methodology that facilitates downscaling of coarser-resolution scenarios to local-scales. The research was undertaken with the aim of improving understanding of the impacts of climatic and socio-economic changes upon sensitive landscapes, in particular, wetlands.

As part of this research, a framework was developed which identified problems associated with downscaling scenarios to local-scales alongside some possible solutions to help overcome them. The potential for scenarios to be utilised in spatial planning was also explored and a land cover model developed and implemented using a Geographic Information System (GIS) which downscaled regional-scale land use data. A set of downscaled land cover maps, representing a range of possible futures, were output as part of this process. Subsequently, these maps were utilised to identify land parcels of suitable habitat for two breeding wader species and their potential contribution to national conservation targets. Furthermore, the usefulness of downscaled scenarios to local decision-makers was also examined.

This final chapter draws upon findings from the preceding chapters in order to consider the overall benefits and pitfalls of downscaling coarser-resolution scenarios to local landscapes. The implications of the research findings are discussed and some recommendations for further work are explored.

1.1. Summary of principal findings

Chapter 2 initially identified four problems associated with applying coarser-resolution scenarios and land cover data to local landscapes. These problems comprised; identifying a range of relevant scenarios from the literature, identifying the most suitable set of scenarios for a local landscape, improving the relevance of scenario narratives to the local context and spatialising the outputs to the land parcel level. A methodology was then presented that provided possible solutions to deal with them. This research highlighted the importance of local-scale datasets, particularly landscape characterisation data, in providing input into downscaling processes. Crucially, these local-scale datasets were able to provide insight into future drivers of change and provided a spatial framework through which scenarios may be downscaled.

Key findings comprised the ability to adapt pre-existing scenarios from national-scale scenario-based projects and the reduced need for input and resources in the downscaling process. Other findings suggested that the land parcel scale outputs developed in this research may provide a range of potential benefits for local decision-makers and land managers. These benefits include guiding development planning legislation, for example Local Development Frameworks, and to planners undertaking zoning of land parcels as the outputs delineate potential pressures that individual land parcels might experience in the future. A potential implication of these findings is that the land parcel scale outputs may provide input into localised studies of cartographic visualisations of pressures for change, visual amenity planning or studies of landscape fragmentation.

Chapter 3 focussed upon the potential value of scenarios in spatial planning and decision-making and highlighted the inability of many current scenarios to be applied within local landscapes due to their relatively poor spatial resolution. As a result, a GIS Multi-Criteria Decision Analysis (GIS-MCDA) was undertaken that generated locally explicit land cover change maps from coarser regional-scale data. The purpose was to investigate the medium- to long-term impacts of socio-economic and climatic change upon local landscapes. The downscaled land cover maps formed the basis of analyses presented in subsequent chapters. Findings suggested that high spatial resolution data may be generated using minimal input from multiple engagement or consultation exercises and an advantage was that focus is able to be maintained upon mapped outputs, rather than the step-by-step complexities of modelling. Thus, these findings suggested that the methodology presented may be appealing to local decision-makers working with limited capacity.

Additional findings from this research comprised the integration of a randomising factor within the GIS-based land cover model. This factor helped to resolve issues of spatial incongruence and the plausibility of mapped outputs by assisting the GIS in selecting between cells of similar suitability. A potential implication of the research is that the random factor may be utilised in further studies to facilitate communication of uncertainty, particularly with regard to the likelihood that certain land parcels may transition in the future. Thus, a potential implication of these findings is that the downscaled outputs may provide input into landscape planning and management processes.

Chapter 4 highlighted some limitations of current nature conservation policy, specifically that they do not take into account the potential impacts of future change upon natural resources, despite evidence indicating that socio-economic and climatic changes are already taking place. As a result, this research developed and implemented an approach that facilitated land parcels of suitable habitat for two breeding wader species (redshank and bittern) to be derived using knowledge of future land cover change. Two scenarios representing different levels of land management, implemented under Environmental Stewardship prescriptions available to farmers, were utilised as part of this process that may create conditions favoured by either wader species.

One of the key findings emerging from this work is our capacity to provide large areas of suitable habitat for breeding waders which may help reverse long-term declines in population and contribute towards UK nature conservation targets, specifically those set under the UK Biodiversity Action Plan (UKBAP). The vast majority of land parcels were located upon low agricultural grade and flood-prone land, meaning that they may be potentially suitable for reversion. Other findings indicated that the majority of these land parcels were currently entered into low-level management schemes (i.e. Entry Level Stewardship) and may benefit from more concerted levels of land management (i.e. Higher Level Stewardship). A potential implication of these findings is that if funding to farmers entering their land into Higher Level Stewardship were to increase and be made more readily available, then widespread improvements in number and distribution of breeding wader species may be realised.

In Chapter 5, the focus of the thesis centred upon investigating the usefulness of downscaled scenarios to end-users. To achieve this, semi-structured interviews were undertaken with local decision-makers which focussed upon four topics of discussion, including: establishing familiarity with scenarios and their current level of use, comparing interpretations of regional-scale and downscaled scenarios, identifying benefits and limitations of the approach and examining the potential role of downscaled scenarios in local decision-making.

This research identified a number of key findings, perhaps most important was the ability of downscaled scenarios to provide an extra level of detail to decision-makers that was not provided by traditional coarser-scale scenario outputs. Other findings indicated that the downscaled scenarios served to reinforce the potential spatial extent of landscape changes and helped to elicit questions from decision-makers regarding the practicality of wider landscape change within Broadland. Therefore, a potential implication of these findings is that the downscaled scenarios might be useful in instigating debate regarding Broadland’s range of possible futures. An additional finding focussed upon the input of downscaled scenarios into landscape visualisations and participatory-GIS that aim to engage people with the potential impacts of future socio-economic and climatic changes upon landscapes. Whilst more detailed local validation and ground-truthing were required by decision-makers before they were able to be utilised in formal decision-making processes, the downscaled scenarios presented provide a useful starting point from which additional outputs may be generated.

1.2. Strengths and limitations

Inherently, there are strengths and some limitations to the research as presented. Indeed, many of these have already been discussed within individual chapters and are therefore not repeated here. Instead, general discussion is presented centred on some of the key issues emerging from this research.

A particular strength is that the study has been able to produce spatially detailed datasets from coarser-scale input data that may be useful to a range of decision-makers, including planners and land managers. As part of this process, the study has attempted to retain consistency with the foundations of scenarios research, in particular, by maintaining transparency and reproducibility of the approach, and its outputs (Shackley and Deanwood, 2003; Alcamo, 2008). In doing so, the research has added to our understanding of investigations involving environmental change by utilising datasets from different spatial scales; as advocated by a number of other researchers (Verburg, 2000; Adger et al. 2005; Wilbanks and Kates, 1999). In addition, the research has employed both qualitative and quantitative datasets in the downscaling process which has been a preference of scenarios research for some time (Schwartz, 1991; Shearer, 2005). This is due to the inherent benefits of combining the well-documented and transparent inputs of quantitative models with understandable narratives provided by qualitative datasets (Alcamo, 2008).

A strength is that the downscaled scenarios output as part of this research may provide input into current policies and strategies governing local landscapes. In general, overall policies (i.e. the Broads Plan 2004 - Broads Authority, 2007), provide input into habitat strategies (e.g. Fen management strategy – Broads Authority, undated), which culminate in projects or tasks which deliver goods and services on the ground (e.g. the Bittern II and Trinity Broads projects – see Broads Authority, 2010). The outputs presented in this research may feed directly into these projects by providing an evidence base for project planning or feasibility studies at the landscape-scale. For example, to decision-makers undertaking biodiversity opportunity mapping exercises, downscaled scenarios may provide input into sensitivity scoring of habitats vulnerable to land cover change; thereby forming an important linkage with existing scenario-based studies which provide data at the national- or regional-scale such as UKCIP or RegIS. Perhaps most importantly, downscaled outputs may then provide feedback into current policies and strategies, such as the Broads Plan and Fen management strategy (among others), to assist the delivery of targeted schemes that aid land management.

A further strength is that the research undertaken has utilised local-scale datasets, such as landscape characterisation data, to provide input into the downscaling process. The strength of this approach is that such datasets take into account local contexts which include issues of local responses to environmental perturbation and associated drivers of change (Alcamo, 2008; Fairclough et al. 2002). In addition, localised datasets are able to provide insight into problems and threats of environmental change which are not included in coarser-scale perspectives taken by national- and regional-scale datasets (Land Use Consultants, 2006; Millennium Ecosystem Assessment, 2005; Wilbanks, 2002). As a result, the downscaled scenarios generated as part of the wider research project have additional benefit. Firstly, the local-scale scenarios were produced under assumptions consistent with those used for coarser-scale scenarios, and hence may provide insight into the spatial variability of national- and regional-scale scenarios that is otherwise unavailable (Dőll et al. 2008), and; secondly, producing scenarios using multiple spatial scales can serve to act as checks of the consistency and plausibility of one another and help to ground-truth models used to generate coarser-resolution scenarios (Schoemaker, 1995; Alcamo et al. 2006).

Despite these strengths, there are caveats. Perhaps most significantly there are a number of uncertainties inherent in scenario-based approaches and these are likely to have been replicated in the work presented here. Indeed, although potential influences of uncertainty are acknowledged in this research and have aimed to be investigated where possible (e.g. sensitivity analysis presented in Munday et al. 2010), many do still remain.

There are uncertainties associated with the likelihood that certain drivers of change may become more influential and therefore their resultant futures may too be affected (Alcamo, 2008). This is especially true over longer timescales as uncertainties become exaggerated and futures become even less clear (Shearer, 2005). A relevant example is in the case of policy-based drivers, specifically those which speculate future agricultural change, as some quite drastic changes in policy may impart unexpected landscape modifications (such as decoupling of agricultural subsidy payments to production seen in 2005 – Dobbs and Pretty, 2008) and they may also be liable to change over inconsequential (i.e. much shorter) timescales than are relevant to the scenario(s) in question (Land Use Consultants, 2006; Dockerty et al. 2006). A particularly relevant example is reforms to the European Union’s Common Agricultural Policy due in 2013. Such restructuring at this time may drive further landscape changes which may not have been expected (Buckwell, 2008) and therefore are not encompassed by the scenarios presented in this study. Consequently, despite attempts to investigate and reduce the impacts of potential uncertainties where possible, the work as presented comprises a number of uncertainties which may limit their potential value, and legitimacy, amongst the users that they are intended for; this is especially true in landscapes that are environmentally sensitive and where a particular form of land management (agriculture) dominates the landscape. Possible extensions to the research, including addressing issues of uncertainty, are discussed in more detail in the section that follows.

Whilst the research presented here has produced a range of downscaled outputs using coarser-scaled data which were intended for use by local decision-makers, it is acknowledged that a stronger component of stakeholder engagement may ultimately have improved the value of these outputs to end-users. Indeed, the benefits of utilising stakeholder and expert consultations in scenarios research are already well-documented (Shackley and Deanwood, 2003; Sheppard et al. 2005; Wollenberg et al. 2000). For example, it is suggested that the intended audience for which outputs are expected to be used by may feel disassociated and untrusting of works to which they have had limited input (Wilbanks and Kates, 1999; Nicholson-Cole, 2005); although this was not a feeling communicated in interviews presented in this thesis (Chapter 5). This is despite the fact that downscaled outputs may be directly relatable to other widely adopted, and credible, projects (for example, like those scenarios produced here may be directly related to those of the UKCIP and RegIS projects – UKCIP, 2001; Holman and Loveland, 2002). Yet, developing entirely ‘new’ scenarios from the ground-up, which incorporate multiple engagement exercises are costly, both in monetary terms but also with regard to time necessary to prepare, undertake and feedback to stakeholder groups (using multiple facilitators, a timescale of between two to three years can typically be expected – Alcamo, 2008). As a result, this approach was unfeasible for the work presented in this thesis. Nevertheless, an alternative procedure for the outputs generated here might involve utilising these datasets as a starting-point whereby stakeholder and expert opinions may be incorporated and additional outputs generated. This approach will undoubtedly entail lower costs and hence may be particularly appealing to local decision-makers working with limited capacity.

One of the pertinent questions that this type of research output evokes concerns the debate of accuracy versus precision. Accuracy typically refers to the degree to which information, perhaps on a map or in a digital database, matches true or accepted values whilst precision can be defined as the level of measurement or exactness of description in a GIS database (Brimicombe, 2003). It is noteworthy that neither accuracy nor precision are mutually exclusive. Indeed, high precision does not necessarily indicate high accuracy nor does high accuracy imply high precision; the pursuit of both high accuracy and high precision is costly and often unattainable in most applications (Bauer and Steinnocher, 2001). Consequently, issues of accuracy and precision tend to be common themes amongst researchers working with finer-scale spatial (see Scott et al. 2003; Wear and Bolstad, 1998). This too is a theme replicated in the research presented here. For example, whilst the implemented land cover model may operate at a spatially precise scale (e.g. cells of 5 m^2) the mapped outputs imply a certain level of accuracy by their nature which may appear misleading or unrealistic to stakeholders or non-experts to which they are targeted. Indeed, the selection of a 5 m^2 cell resolution may appear a poor surrogate for representing decisions of land managers (e.g. farmers) where decisions are typically made at the land parcel level (Evans et al. 2001). In this sense, the mapped outputs may appear more accurate than intended and may portray an implied level of certainty about potential future worlds. The issue of implied accuracy, and uncertainty, may be particularly problematic if model outputs were intended for display or for public consultation and were presented without clarifying detail. In recent times, conservation bodies have had to refrain from presenting future scenarios with recognisable local landscapes (see BBC, 2008). Consequently, we suggest that an alternative method that may be adopted in future studies would be to model at the land parcel rather than cell level or to aggregate mapped outputs up to an appropriate level (i.e. Landscape Character Area) where the changes that are implied are less likely to be misconstrued or misinterpreted.

Whilst focus has been maintained upon the advantages of utilising downscaled outputs over existing coarser-resolution scenarios throughout this research, including generating spatially detailed maps from coarse inputs or utilising multi-scale inputs, comparison with finer-scale models (e.g. those of Jenerette and Wu, 2001; Mena et al. 2011) suggests that these benefits might be more appropriately framed. For example, Jenerette and Wu (2001) demonstrate a fine-scale (75 m^2 resolution) land use model using input from historical maps and topographic data to reconstruct past changes in land use. Their model is able to replicate historical changes, albeit across a limited number of land use categories, whilst simultaneously providing forecasting functionality. In contrast, the model presented in this research has not been parameterised to provide any back-casting functionality. Furthermore, fine-scale agent-based models, such as that of Mena et al. (2011), are able to utilise multi-scale inputs including satellite remote sensing, topographic data and household surveys to model land use with both high accuracy and precision. By their nature, agent-based models (consisting of both cellular-automata and an agent-based module, or decision-set, which act as a surrogate for decision-making processes – see Parker et al. 2001) are able to replicate decisions across a range of spatial scales. For example, decisions are made at the cell, the parcel (i.e. group of similarly categorised cells, such as a land cover) and farm or household level rather than just at the cell (5 m^2) level as adopted here. Such models also have an advantage in that they are able to imitate dynamic systems, such as migration patterns and changes in demographics. Consequently, whilst the land cover model implemented in this research is an improvement on many coarser-resolution models, the inability to incorporate agent-based decision rules and back-casting functionality is an area in which the model is potentially lacking.

A further limitation is the reliance upon the current Environmental Stewardship payment scheme to provide suitable habitat for breeding wader species, as presented in Chapter 4. In this work, conservation opportunities for two breeding wader species (bittern and redshank) were derived using knowledge of future land cover change. Key to this procedure was the focus upon a range of management options available to land managers (farmers) under Entry Level Stewardship and Higher Level Stewardship agreements that may create habitat favoured by either wader species.

Recent research highlights a dilemma caused by the UK's current two-tiered system of Environmental Stewardship (Ausden and Hirons, 2002; Winder and Armstrong-Brown, 2001). In particular, a question remains whether more intensive and less widespread management (i.e. Higher Level Stewardship) or less intensive and more abundant management (i.e. Entry Level Stewardship) is the best method for providing suitable habitat (Eglington, 2008). Indeed, in the past, nature reserves have been the areas that have attracted and maintained the greatest populations of species (Ausden and Hirons, 2002), and these areas have tended to incorporate more intensive methods of land management across a small number of high quality habitats.

Contrastingly, the current Environmental Stewardship system aims to establish a greater number of relatively poorer quality habitats and a tradeoff therefore exists between the quantity and quality of habitat that is available (Ausden and Hirons, 2002). It is clear that habitat created under Entry Level Stewardship is insufficient on its own, thus Higher Level Stewardship is likely to be the mechanism by which favourable habitat may be created to attract breeding wader species (Wilson et al. 2004). However, limited financial resources and the attractiveness for farmers to continue to grow cereals (due to rising prices - United States Department of Agriculture, 2010) means that the creation of favourable habitat for breeding waders under Higher Level Stewardship is unlikely to materialise in the near future (Buckwell, 2008; DEFRA, 2010). An alternative to the current UK system perhaps lies in a system endorsed in other parts of Europe (specifically, the Netherlands), whereby groups of land managers have applied to implement Environmental Stewardship options and they have worked together to create larger areas (over 100 ha) of high quality habitat (Kleijn et al. 2004). Consequently, in light of these arguments, it will be a challenge to reverse current declines and maintain a long-term increase in breeding wader numbers under the present system due to financial restrictions, and this should be borne in mind when considering the implication of results presented in Chapter 4.

Alongside these strengths and limitations a number of recommendations emerge for researchers undertaking similar studies and to future scenario development exercises in general. The methodology as presented is reliant upon the breadth and diversity of literature output as part of scenario development exercises. Therefore it is a recommendation of this research that to be utilised in local-scale studies, scenario-based projects seek to provide a greater diversity of quantitative and qualitative outputs as part of the scenario development process. For example, the presence of detailed scenario narratives, as provided by the UKCIP scenarios, was critical to the development of localised narratives for the Broadland case study area. Likewise, regional-scale land use change data, such as that provided by RegIS, was able to add a further spatial dimension to this study which is often lacking in many other scenario-based projects (e.g. State of the Countryside, 2020 – Countryside Agency, 2003; Rural Futures – Future Foundation, 2005).

However, the relatively high cost of producing quantitative outputs may be a barrier to projects with limited budgets and it is also recognised that producing such outputs may not be a goal that is highly valued by stakeholders.

1.3. Recommendations for further work

A limitation of this work was the lack of consideration afforded to 'extreme' events or sudden unexpected changes as part of the downscaling process. Indeed, the lack of integration of extreme events in scenario-based studies is a widely cited criticism and may help to reduce the range of uncertainties associated with the scenarios (e.g. Katz and Brown, 1992; Wagner, 1996; Schwartz and Randall, 2003). Research suggests that scenarios tend to focus upon the accumulation of changes over time that all point towards a similar goal (Abildtrup et al. 2006). However, not all change is this straightforward, particularly that involving landscapes (Munday et al 2010). Drivers of change may vary over time, with one driver having greater influence than another at any given moment (Chermack et al. 2001). For example, in recent times inflated prices of cereals, particularly wheat, have driven change in cropping practises by many nations dependent upon income from exports (Choices, 2008). If change is gradual, one scenario may be seen to supersede another (e.g. a shift from a Global Sustainability future to Regional Enterprise might occur). Where changes are sudden, further questions may be evoked regarding the resilience of the scenario(s) to its impacts (Berkhout et al. 2002). Therefore, the implications of incorporating extreme events or sudden changes within the scenarios presented are potentially multifaceted and complex. Nevertheless, consultation exercises may be utilised to incorporate sudden or extreme events within the scenarios adopted in this study. A possible solution would involve applying presupposed changes to each of the scenarios and trying to assess how robust scenario drivers were to these changes (see Berkhout et al. 2002).

The downscaled outputs presented in this thesis, particularly land cover maps, are limited in their ability to consider multiple viewpoints or to allow variations in spatial scale to occur, for example, by allowing viewers to focus upon particular localities and to view changes that may transpire on-the-ground. This is an especially important characteristic, particularly if the outputs were to be employed as part of a wider process of public engagement (Appleton, 2003). Indeed, 2-dimensional images, including those incorporating aerial viewpoints, may be difficult for individuals to engage with as they present perspectives which may be unfamiliar (Nicholson-Cole, 2005; Sheppard, 2001). A natural extension to this work therefore might involve incorporating the downscaled land cover maps into 3-dimensional landscape visualisations, developed using specialised GIS (e.g. Visual Nature Studio - 3D Nature, 2003). Numerous examples exist which provide localised case studies representing future landscape change (see Appleton et al. 2002; Dockerty et al. 2005; 2006; Tress and Tress, 2003) and studies are also available for the Broadland study area (Jones et al. 2006); this may negate the development of a comprehensive image library of local vegetation required for creating visualisations which are often time-consuming (Sheppard, 2001).

Finally, given the high spatial resolution of the outputs generated in this research and their consideration of wider landscape changes, a further possibility for extending the study may focus upon analysis of fragmentation and connectivity (e.g. Hill et al. 1999; Dale et al. 2002; Southern, 2008). Recently, much attention has been paid within the field of landscape ecology upon increasing our efforts to conserve biotic resources by reducing fragmentation of habitats through a system of recreating natural connections or 'corridors' (Beier and Noss, 1998; Donald and Evans, 2006). Indeed, examples exist which have attempted to delineate possible solutions (e.g. Jones et al. 2006; Southern, 2008). Therefore, it is possible that the downscaled land cover maps generated in this research project may provide useful input into fragmentation and connectivity analyses. This may in-turn feedback into current nature conservation policy governing threatened habitats (e.g. grazing marshes and fen, Local Biodiversity Action Plan – Broads Authority, 2009) and aid local planners undertaking surveys which identify re-connection opportunities.

1.4. Closing remarks

The research presented in this thesis has demonstrated a procedure for downscaling datasets to local landscapes that describe future climatic and socio-economic changes. This is a critical period for many landscapes, particularly those sensitive to change, such as wetlands, as a variety of pressures begin to challenge their sustainability. There now exists an opportunity to examine a range of potential futures through using scenarios. Results from this thesis suggest that downscaling existing scenarios to local landscapes holds the potential to provide useful input into environmental decision-making processes and may help us to gain greater understanding of how sensitive landscapes may react to future uncertainties.

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Supplementary Material

Appendix

This document provides a procedural reference guide that was developed to describe GIS-based modelling of land use change within the Norfolk Broads (Broadland) study area to 2100, the outputs of which provide the basis for analysis in many of the resultant chapters in this thesis.

Note: text within dashed boxes appears frequently throughout this document to provide users with additional information and for some discussion of the main limitations and assumptions inherent in undertaking the different procedural steps.

1. Creating raw OS Mastermap grid layer

In ArcMAP

An example is given here for one (grid 536_31) of the 40 five by five kilometre grid squares covering the Broadland study area. The processes described here were repeated for each of the 40 grid squares.

Add all individual final land use layers derived in Chapter 2 – A framework for developing high resolution scenarios at the landscape-scale: the Norfolk Broads (Table 3.1 describes this procedure), into ArcMap: *536_31arableg, 536_31permgrassg, 536_31recreg, 536_31roadsFINAL, 536_31unculteraseg, 536_31urban1g, 536_31water* and *536_31woodlandg*.

Open attribute table of each layer and add new field “LANDUSE”. Code each land use accordingly:

Arable = 1
Permanent grassland = 2
Recreation = 3
Roads = 4
Uncultivated = 5
Urban = 6
Water = 7
Woodland = 8

To merge all grid land uses into single land use grid

Merge all final grid layers together e.g.:
536_31arableg
536_31permgrassg
536_31recreg
536_31roadsFINAL
536_31unculteraseg
536_31urban1g
536_31water
536_31woodlandg
Output saved as *536_31landuse*

Delete all unnecessary fields to help reduce processing time.

To identify NoData areas (these needed to be coded to ‘0’ for IDRISI to recognise them)

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31* (i.e. the grid layer)
Erase features = *536_31landuse* (i.e. the merged land use layer)
Output features = *536_31landuseERASE*

To add NoData (‘0’) landuse to attribute table

Open attribute table of *536_31landuseERASE*

OPTIONS>ADD FIELD
Add new field ‘LANDUSE’
Right-click field header>FIELD CALCULATOR
Set LANDUSE = 0

To create final land use layer (merge-erase polygon and other layers)

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31landuseERASE* and *536_31landuse*
Output saved as *536_31landuseFINAL*

To convert final land use layer to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *536_31landuseFINAL*
Field = LANDUSE
Output cell size = 5
Output saved as *landuse536_31*

To convert raster to ASCII (for importing into IDRISI)

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *landuse536_31*
Output saved as *lu536_31_1995MMAP* (with .asc extension)

In IDRISI

Change Working Folder to E:\Data\IDRISI\zGRID\536_31

To import landuse layer

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER BINARY FORMAT TO IDRISI
Choose to CONVERT OUTPUT FILE FROM REAL TO INTERGER
Choose to keep REFERERENCE SYSTEM = PLANE, UNITS = METRES, UNIT DISTANCE = 5
Input file = *lu536_31_1995MMAP*
Output file = *lu536_31_1995MMAP*

2. Creating individual Boolean land use images

For input into IDRISI’s land use module, a Boolean/binary image (i.e. containing simply 0s and 1s) is required for each land use category. This ensures that if change occurs, albeit even a marginal change, the model is able to account for any changes in the spatial extent of each land use category. Whilst the module is able to facilitate modelling of change in land use extent, the relatively simplistic categorisation required as inputs may be considered unrealistic in the context of real-world land management/planning decisions. For example, it is unlikely that a land manager or planner is able to totally disregard the selection of a particular land use for any particular land parcel. Indeed, over the last three decades we have witnessed large-scale development within high flood-risk areas, such as the Thames Gateway and the South East areas of the UK, which now appear mis-judged in the context of recent planning legislation (e.g. Planning Policy Statement 25: Development and Flood Risk – see http://www.communities.gov.uk/publications/planningandbuilding/pps25floodrisk). Whilst the model adopted in this work requires the input of Boolean images, an alternative would be to model each land use category as continuous variables, however due to lack of software functionality, this was not attempted here.

In ArcMap

Note: an alternative (raster-based) procedure to that presented here would be to convert the final land use grid (comprising all eight land use categories) from vector to raster, reclassify an individual land use category to 1s and all others to 0s and export to .ascii for input into IDRISI. Then repeat for the remaining land use categories.

To create Boolean image

Open attribute table of *536_31landuseFINAL*
OPTIONS>SELECT BY ATTRIBUTE
Create the following expression (choose GET UNIQUE VALUES):
    "LANDUSE" = 1
DATA>EXPORT
Output saved as *536_31arable*

Add field “BOOL” and code to 1.

To erase arable land from grid

Input features = *536_31*
Erase features = *536_31arable*
Output = *536_31arable01*

Add field “BOOL” and code to 0.

To merge both Boolean shapefiles together

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input features = *536_31arable* and *536_31arable01*
Output = *536_31arablemerge*

To convert from vector to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *536_31arablemerge*
Field = LANDUSE
Output cell size = 5
Output saved as *arab536_31*

To convert raster to ASCII (for importing into IDRISI)

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *arab536_31*
Output saved as *arab536_31* (with .asc extension)
Save output in E:\Data\osmastermap\GRID\536_31\arab522_24

All final layers:
arab536_31
pgrass536_31
recre536_31
roads536_31
uncult536_31
urban536_31
water536_31
wood536_31   Repeat process for all other land use layers

3. Constraint images

Constraint images delineate areas not suitable for the land use in question and are Boolean in nature. They were required by the land use model to map areas which are unable to change for each of the eight land use categories. One of the issues associated with incorporating constraint (i.e. Boolean) images is that they are deterministic in nature (more discussion about the deterministic nature of mapped outputs, and the modelling methodology in general, is provided in Chapters 2 and 6) and this can influence the mapped outputs that are produced. An alternative to modelling some of these constraints (e.g. slope) as Boolean images would be to model them as factors (see section 4). However, to maintain consistency with constraints/factors adopted by the RegIS project this was not attempted here.

In IDRISI

To import landuse layer

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER BINARY FORMAT TO IDRISI
Choose to CONVERT OUTPUT FILE FROM REAL TO INTERGER
Choose to keep REFERERENCE SYSTEM = PLANE, UNITS = METRES, UNIT DISTANCE = 5
Input file = *arab536_31*
Output file = *arab536_31*

Repeat for all other land use layers

To create Constraint image

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *roads536_31*
Output file = *CON536_31_roads*

Assign a new value of = 1	To all values from = 0	To just less than 1
Assign a new value of = 0	To all values from = 1	To just less than 2

Click OK

Repeat for Urban and Water layers

3.1. Constraint – Slope

In ArcMap

To clip Digital Terrain Model (DTM) to five kilometre grid

Add layer *dtmfinal_clip*
DATA MANAGEMENT TOOLS>RASTER>CLIP
Input raster *dtmfinal_clip*
Output extent (open 536_31>SOURCE) and input X and Y values accordingly
Output raster = *dtm536_31*

To convert raster to ASCII (for importing into IDRISI)

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *dtm536_31*
Output saved as *dtm536_31* (with .asc extension)

In IDRISI

To import DTM layer

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER BINARY FORMAT TO IDRISI
Choose to keep REFERERENCE SYSTEM = PLANE, UNITS = METRES, UNIT DISTANCE = 1
Input file = *dtm536_31*
Output file = *dtm536_31*

To derive slope as percentage

GIS ANALYSIS>CONTEXT OPERATIONS>SURFACE
Calculate = SLOPE
Input elevation model = *dtm536_31*
Output slope image = *536_31slope*
Calculate slopes in = PERCENT
Conversion from unspecified to meters = 1

To identify suitable/unsuitable slopes

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *536_31slope*
Output file = *CON536_31_slope*

Assign a new value of 1	To all values from 0	To just less than 11
Assign a new value of 0	To all values from 1	To just less than 999

3.2. Constraint – Designated areas

To clip Ramsar shapefile to grid

ANALYSIS TOOLS>EXTRACT>CLIP
Input features = *ramsar*
Clip features = *536_31*
Output = *536_31desig*
Add new field "BOOL" and code to 1.

To erase designation areas from grid

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31*
Erase features = *536_31desig*
Output = *536_31desig01*
Add new field "BOOL" and code to 0.

To merge shapefiles together

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Merge features = *536_31desig* and *536_31desig01*
Output = *536_31desigmerge*

To convert from features to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *536_31desigmerge*
Field =BOOL
Output cell size = 5

Output saved as *desig536_31*

To convert raster to ASCII (for importing into IDRISI)

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *desig536_31*
Output saved as *desig536_31* (with .asc extension)

In IDRISI

To import DTM layer

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER BINARY FORMAT TO IDRISI
Choose to keep REFERERENCE SYSTEM = PLANE, UNITS = METRES, UNIT DISTANCE = 1
Input file = *desig536_31*
Output file = *desig536_31*

To reclassify image for constraint format

GIS ANALYSIS>DATABASE QUERY
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *desig536_31*
Output file = *CON536_31_desig*
Assign a new value of 1 To all values from 0 To just less than 1
Assign a new value of 0 To all values from 1 To just less than 2

All Constraint images:
CON536_31_desig
CON536_31_roads
CON536_31_urban
CON536_31_water

4. Factor images

Unlike constraint images, factor images are continuous in nature (e.g. distance) and indicate the relative suitability of different areas. A number of steps are required to produce these images including converting from integer to byte format and standardising each of the images to the same scale. Consequently, these steps necessitate a number of assumptions. For example, when incorporating ‘distance from’ images in the land use model (i.e. in the case of agriculture, to take account of distance from market) one assumes that the strength of the relationship decreases with distance.

4.1. Factor – individual land use images and distance from images

To convert from integer to byte data type

REFORMAT>CONVERT
File type = IMAGE
Input file name = *arab536_31*
Output file name = *ARAB536_31BYTE*
Output data type = BYTE
Output file type = BINARY
Conversion type = ROUNDING

Repeat for all other land use layers

All files:
ARAB536_31BYTE
PGRASS536_31BYTE
RECRE536_31BYTE
ROADS536_31BYTE
UNCULT536_31BYTE
URBAN536_31BYTE
WATER36_31BYTE
WOOD536_31BYTE

To calculate distance image

GIS ANALYSIS>DISTANCE OPERATORS>DISTANCE
Feature image = *ARAB536_31BYTE*
Output image = *DIST536_31_arable*

Repeat for all relevant land uses

All files:
DIST536_31_arable
DIST536_31_recre
DIST536_31_roads
DIST536_31_urban

To standardise distance images

GIS ANALYSIS>DECISION SUPPORT>FUZZY (i.e. a continuous relationship is present)
Membership Function Type = LINEAR (i.e. areas closest to land use are best)
Input file = *DIST536_31_arable*
Output file = *FACTOR536_31_arabledist*
Output data format = BYTE
Membership Function Shape = MONOTRONICALLY DECREASING
Control point c = 0 (lowest value)
Control point d = 867.65 (highest value)

To create individual land use image

GIS ANALYSIS>DECISION SUPPORT>FUZZY
Membership Function Type = LINEAR (i.e. areas closest to land use are best)
Input file = *DIST536_31_arable*
Output file = *FACTOR536_31_arable*
Output data format = BYTE
Membership Function Shape = MONOTRONICALLY DECREASING
Control point c = 0 (lowest value)
Control point d = 5 (highest value)
Repeat for all other land use layers.

All distance files:
FACTOR536_31_arabledist
FACTOR536_31_recredist
FACTOR536_31_roadsdist
FACTOR536_31_urbandist

All land use factor files:
FACTOR536_31_arable
FACTOR536_31_recre

FACTOR536_31_roads
FACTOR536_31_urban

4.2. Factor – agricultural land grade

In ArcMap

To clip alc layer to grid

Add *alc_clipcovallgrids* to map
ANALYSIS TOOLS>EXTRACT>CLIP
Input features = *alc_clipcovallgrids*
Clip features = *536_31*
Output = *536_31alc*

To separate all agricultural grades

Open attribute table of *536_31alc* >OPTIONS>SELECT BY ATTRIBUTES
Method = CREATE NEW SELECTION
Create the following expression (choose GET UNIQUE VALUES):
NAME = GRADE 1
DATA>EXPORT DATA
Output saved as *536_31grade2*

Repeat for other grade(s) applicable within grid.

All files:
536_31grade2
536_31grade3

To identify arable fields within each alc grade

SELECTION>SELECT BY LOCATION
I want to = SELECT FEATURES FROM
the following layer(s) = *536_31arable*
that = ARE CONTAINED BY
the features in this layer = *536_31grade2*
Right-click 522_24arable >DATA>EXPORT DATA
Output saved as *536_31arable_grade2*
Open attribute table of *536_31arable_grade2*, create new field “GRADE” and code to 2

Repeat process for other grades (code as appropriate i.e. to ‘2’ and ‘3’) within grid.

All files:
536_31arable_grade2
536_31arable_grade3

To merge arable fields within alc together into single layer

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31arable_grade2* and *536_31arable_grade2*
Output = *536_31alc_mergeall*

To generate layer representing all other cells in grid (NoData)

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31*
Erase features = *536_31alc_mergeall*
Output = *536_31alc_mergeall_erase*

Open attribute table, add new field "GRADE" and code to '0'

To merge NoData layer and merge layer to create final layer

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31alc_mergeall* and *536_31alc_mergeall_erase*
Output = *536_31alc_mergeallFINAL*

To convert features to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *536_31alc_mergeallFINAL*
Field = GRADE
Output cell size = 5
Output saved as *alcFINAL_31*

To convert raster to ASCII for input into IDRISI

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *alcFINAL_31*
Output = *alcFINAL_31* (with .asc extension)

[Note: suitability classes for arable land were determined as equal-intervals, as follows:]

Class 1	255
Class 2	204
Class 3	153
Class 4	102
Class 5	51

One of the assumptions associated with the process described above is that the above values represent 'equal-interval' classes and do not consider the relative benefits of one agricultural land grade over one another. It reality, it is plausible that the highest quality grade of agricultural land (grade 1, class 1 above) is considerably more desirable to land managers, in terms of crop productivity and therefore profit, than a lower grade. In this case the land manager may place disproportionately greater value upon higher grades than those which are lower. Needless to say, a natural extension to the approach adopted here would be to quantify these class intervals via stakeholder consultation.

In IDRISI

To import new alc layer into IDRISI

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER ASCII FORMAT TO IDRISI
Input file = *alcFINAL_31*
Output file = *alcFINAL_31*

To reclassify classes to suitability values

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *alcFINAL_31*
Output file = *FACTOR536_31_alcFINAL*

Assign a new value of	To all values from	To just less than
204	2	3
153	3	4
0	0	1

4.3. Factor – permanent grassland agricultural land grade factor

In order to take into consideration the likelihood that land managers might revert areas of permanent grassland into productive agricultural land, the underlying agricultural land grade classification was determined, such that areas of permanent grassland overlaying the highest grades of agricultural land were reverted in the first instance. This procedure inevitably assumes that land managers are profit maximising i.e. they will chose to revert those areas of permanent grassland that overlay the highest quality land in order of grade. Whilst this might not be necessarily feasible in all instances, this assumption was deemed appropriate for the procedure presented here.

In ArcMap

To identify pgrass areas within each alc grade

SELECTION>SELECT BY LOCATION
I want to = SELECT FEATURES FROM
the following layer(s) = *536_31pgrass*
that = HAVE THEIR CENTROID IN
the features in this layer = *536_31grade2*
Right-click 522_24arable >DATA>EXPORT DATA
Output saved as *536_31pgrass_grade2*
Open attribute table of *522_24pgrass_grade2*, create new field “GRADE” and code to 2.

Repeat process for other grades (code as appropriate i.e. to ‘2’ and ‘3’) within grid

All files:
536_31pgrass_grade2
536_31pgrass_grade3

To merge pgrass fields within alc together into single layer

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31pgrass_grade2* and *536_31pgrass_grade3*
Output = *536_31alc_pgrassmergeall*

To generate layer representing all other cells in grid (NoData)

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31*
Erase features = *536_31alc_pgrassmergeall*
Output = *536_31alc_pgrassmergeall_erase*
Open attribute table, add new field “GRADE” and code to ‘0’

To merge NoData layer and merge layer to create final layer

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31alc_pgrassmergeall* and *536_31alc_pgrassmergeall_erase*
Output = *536_31alc_pgrassmergeallFINAL*

To convert features to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *536_31alc_pgrassmergeallFINAL*
Field = GRADE
Output cell size = 5
Output saved as *alcpgrass_31*

To convert raster to ASCII

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *alcpgrass_31*
Output = *alcpgrass_31* (with .asc extension)

In IDRISI

To import new alc layer into IDRISI

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER ASCII FORMAT TO IDRISI
Input file = *alcpgrass_31*
Output file = *alcpgrass_31*

To reclassify classes to suitability values

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *alcpgrass_31*
Output file = *FACTOR536_31_alcpgrass*

Assign a new value of	To all values from	To just less than
102	2	3
153	3	4
0	0	1

4.4. Factor - EA Flood Map factor for arable

In ArcMap

To clip EA Flood Map to grid

ANALYSIS TOOLS>EXTRACT>CLIP
Input features = Floodzone2
Clip features = *536_31*
Output = *536_31FZ2*

To identify arable fields within flood zone

SELECTION>SELECT BY LOCATION
I want to = SELECT FEATURES FROM
the following layer(s) = *536_31arable*
that = HAVE THEIR CENTROID IN
the features in this layer = *536_31FZ2*
Right-click *536_31arable*>DATA>EXPORT DATA
Output saved as *536_31FZ2arable_in*
Open attribute table of *536_31FZ2arable_in*, create new field “FLOODZONE” and code to 2

To create layer representing area outside of the flood zone

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31*
Erase features = *536_31FZ2*
Output = *536_31eraseFZ2*

To identify arable fields outside of flood zone

SELECTION>SELECT BY LOCATION

I want to = SELECT FEATURES FROM
the following layer(s) = *536_31arable*
that = HAVE THEIR CENTROID IN
the features in this layer = *536_31eraseFZ2*
Right-click *536_31arable*>DATA>EXPORT DATA
Output saved as *536_31FZ2arable_out*
Open attribute table of *536_31FZ2arable_out*, create new field "FLOODZONE" and code to 1

To merge arable fields inside and outside together

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31FZ2arable_in* and *536_31FZ2arable_out*
Output = *536_31FZ2arableMERGE*

To identify all other background cells not considered (NoData)

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31*
Erase features = *536_31FZ2arableMERGE*
Output = *536_31FZ2arableMERGEERASE*
Open attribute table, create new field "FLOODZONE" and code to 1

To merge arable fields and NoData cells together to form final FZ2 layer

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *536_31FZ2arableMERGE* and *536_31FZ2arableMERGEERASE*
Output = *536_31FZ2arableFINAL*

To convert from features to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *536_31FZ2arableFINAL*
Field = FLOODZONE
Output cell size = 5
Output = *FZ2_536arable*

To convert raster to ASCII

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *FZ2_536arable*
Output = *FZ2_536arable* (with .asc extension)

All files:
FZ2_536arable

In IDRISI

To import floodzone image

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER ASCII FORMAT TO IDRISI
Input file = *FZ2_536arable*
Output file = *FZ2_536arable*

To reclassify classes to suitability values

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *FZ2_536arable*

Output file = *FACTOR536_31_FZ2arable*

Assign a new value of	To all values from	To just less than
255	2	3
128	1	2
0	0	1

4.6. Factor – Elevation

To standardise elevation image

GIS ANALYSIS>DECISION SUPPORT>FUZZY
Membership Function Type = LINEAR (i.e. areas closest to recreation are best)
Input file = *dtm536_31*
Output file = *FACTOR536_31_elev*
Output data format = BYTE
Membership Function Shape = MONOTRONICALLY DECREASING
Control point c = -1.05 (lowest value)
Control point d = 29.60 (highest value)

4.7. Factor – designation (pref yes and pref no)

The four scenarios ('Regional Enterprise and High climate scenario', 'Global Sustainability and Low climate scenario', 'High' and 'Low climate scenarios only') required different methodologies for their development due to the range of drivers influencing scenario storylines. This required the four scenarios to be separated into two groups, namely 'Regional Enterprise and High climate scenario' with 'High climate scenario only' and 'Global Sustainability and Low climate scenario' with 'Low climate scenario only'. As a consequence different weightings, factors and constraints were utilised to be representative of the types of changes described by associated scenario storylines. More discussion of these differences is provided in Chapter 3.

In the case presented here, designated areas, for example Sites of Special Scientific Interest (SSSI) were afforded protected status under the Global Sustainability and Low climate scenario only. This scenario suggests that designated areas will maintain their protected status and that individuals' place particular value upon natural resources. As a result, all areas with designated status were included as constraints in the modelling process under Global Sustainability. Conversely, under the Regional Enterprise and High climate scenario, where designated areas lose their importance and there is less concern for the environment, designated areas were modelled such that changes were able to be made to their spatial extent. Nevertheless, whilst government policy protecting designated areas is particularly weak under the Regional Enterprise future, there is still value placed upon maintaining them. As a result, under the Regional Enterprise future, designated areas were afforded lower weighting than other available land so that development was still possible if necessary.

To reclassify constraint image (pref no)

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *CON536_31_desig*
Output file = *FACTOR536_31_desigprefno*

Assign a new value of	To all values from	To just less than
255	1	2
128	0	1

To reclassify constraint image (pref yes)

GIS ANALYSIS>DATABASE QUERY>RECLASS
Type of file to reclass = IMAGE
Classification type = USER-DEFINED RECLASS
Input file = *CON536_31_desig*
Output file = *FACTOR536_31_desigprefyes*

Assign a new value of	To all values from	To just less than
128	1	2
255	0	1

All files:
FACTOR536_31_desigprefno
FACTOR536_31_desigprefyes

5. Creating suitability images

To create new arable suitability image

GIS ANALYSIS>DECISION SUPPORT>MCE
MCE procedure to be used = WEIGHTED LINEAR COMBINATION
Constraints (four):
CON522_24slope
CON522_24roads
CON522_24urban
CON522_24water

Factors (seven):	Weights
FACTOR536_31_arable	0.3166
FACTOR536_31_pgrass	0.0721
FACTOR536_31_recre	0.0504
FACTOR536_31_wood	0.0246
FACTOR536_31_alcFINAL	0.2345
FACTOR536_31_FZ2arable	0.1603
FACTOR536_31_ARABLERANDOM	0.1067
FACTOR536_31_uncult	0.0348

Output image = *SUIT536_31_loGS_arable*

Repeat for all other land use layers (see table overleaf for weights to assign).

All suitability images:
SUIT536_31_loGS_arable
SUIT536_31_loGS_pgrass
SUIT536_31_loGS_recre
SUIT536_31_loGS_roads
SUIT536_31_loGS_uncult
SUIT536_31_loGS_urban
SUIT536_31_loGS_water
SUIT536_31_loGS_wood

Layer	Factor	Rank (hiRE)	Weighting to apply hiRE*	Rank (logs)	Weighting to apply loGS*
Arable	Existing arable	1	0.3166	1	0.3166
	Existing perm. grassland	6	0.0504	5	0.0348
	Recreational land	8	0.0246	6	0.0504
	Existing woodland	5	0.0721	8	0.0246
	Agri. land grade	2	0.2345	2	0.2345
	Floodzone (outside)	3	0.1603	3	0.1603
	Random selector	4	0.1067	4	0.0721
	Existing uncultivated land	7	0.0348	7	0.1067
Pgrass	Existing arable	3	0.1292	5	0.0716
	Existing perm. grassland	1	0.3747	1	0.3747
	Recreational land	7	0.0278	3	0.1292
	Existing woodland	5	0.0716	7	0.0278
	Perm. grassland agri. land grade	2	0.2141	2	0.2141
	Random selector	4	0.1429	4	0.1429
	Existing uncultivated land	6	0.0398	6	0.0398
Recre	Existing arable	7	0.0278	5	0.0716
	Existing perm. grassland	3	0.1292	3	0.1292
	Recreational land	1	0.3747	1	0.3747
	Existing woodland	5	0.0716	7	0.0278
	Distance from urban areas	2	0.2141	2	0.2141
	Random selector	4	0.1429	4	0.1429
	Existing uncultivated land	6	0.0398	6	0.0398
Roads	Existing arable	6	0.0398	6	0.0398
	Existing perm. grassland	3	0.1292	5	0.0716
	Recreational land	7	0.0278	3	0.1292
	Existing woodland	5	0.0716	7	0.0278
	Existing uncultivated land	2	0.2141	2	0.2141
	Random selector	4	0.1429	4	0.1429
	Existing roads	1	0.3747	1	0.3747
Uncult	Existing arable	5	0.0464	5	0.0835
	Existing perm. grassland	2	0.0835	2	0.1507
	Recreational land	3	0.1507	6	0.0464

	Existing woodland	6	0.0324	7	0.0324
	Existing uncultivated land	1	0.4372	1	0.4372
	Random selector	4	0.2498	4	0.2498
Urban	Existing arable	10	0.0165	8	0.0313
	Existing perm. grassland	8	0.0313	7	0.0454
	Recreational land	9	0.0221	6	0.0649
	Existing woodland	7	0.0454	10	0.0165
	Existing uncultivated land	6	0.0649	9	0.0221
	Random selector	4	0.1000	4	0.1000
	Distance from urban areas	2	0.2056	2	0.2056
	Distance from roads	3	0.1388	3	0.1388
	Within designation (pref. no)	5	0.0960	5	0.0960
	Existing urban areas	1	0.2795	1	0.2795
Water	Existing arable	3	0.1338	3	0.1338
	Existing perm. grassland	5	0.0824	5	0.0824
	Recreational land	6	0.0508	6	0.0508
	Existing woodland	8	0.0209	8	0.0209
	Existing uncultivated land	7	0.0307	7	0.0307
	Random selector	4	0.1252	4	0.1252
	Elevation	2	0.2183	2	0.2183
	Existing water	1	0.3378	1	0.3378
Wood	Existing arable	6	0.0398	7	0.0398
	Existing perm. grassland	5	0.0716	6	0.0716
	Recreational land	7	0.0278	5	0.0278
	Existing woodland	1	0.3747	1	0.3747
	Random selector	4	0.1429	4	0.1429
	Existing uncultivated land	3	0.1292	3	0.1292
	Within designation (pref. yes)	2	0.2141	2	0.2141

*hiRE = Regional Enterprise and High climate scenario, logs = Global Sustainability and Low climate scenario only.

6. Creating Rank images

To create rank ordered images from suitability images

GIS ANALYSIS>DECISION SUPPORT>RANK
Input image = *SUIT536_31_loGS_arable*
Output image = *RANK536_31_loGS_arable*
Sort order = DESCENDING (i.e. most suitable areas will have a value closer to 1)
Choose to use secondary sort file
Secondary sort file = *FACTOR536_31_arabledist*
Sort order = ASCENDING (to maintain logic of MOLA, in multiple criteria assessments, ascending ranks must be chosen)

Repeat process for all other suitability images using the associated distance image as a secondary sort file to resolve any tied cells.

All rank images incorporating secondary sort file:
RANK536_31_loGS_arable
RANK536_31_loGS_pgrass
RANK536_31_loGS_recre
RANK536_31_loGS_roads
RANK536_31_loGS_uncult
RANK536_31_loGS_urban
RANK536_31_loGS_water
RANK536_31_loGS_wood

7. Modelling land use change for 2050 scenarios

7.1. 2050loGS scenario

To model 2050loGS land use map using new rank images

GIS ANALYSIS>DECISION SUPPORT>MOLA

Objective caption	**Objective weight**	**Rank image**	**Areal requirements**
Arable	6	*RANK536_31_loGS_arable*	438497
Pgrass	7	*RANK536_31_loGS_pgrass*	138857
Recre	5	*RANK536_31_loGS_recre*	25696
Roads	3	*RANK536_31_loGS_roads*	23836
Uncult	8	*RANK536_31_loGS_uncult*	199940
Urban	1	*RANK536_31_loGS_urban*	60546
Water	4	*RANK536_31_loGS_water*	60664
Wood	2	*RANK536_31_loGS_wood*	51937

Areal tolerance = 0
Output image = *lu536_31_2050loGS_NEWFINAL*

Objective weights were required by the land use model to assist in cases of similar suitability. The weights used reflected a simply ranking (from 1 to 8, with 8 being the greatest weight) of the eight land use maps. Chapter 3 discusses the ranking procedure. In is noteworthy that the objective weights selected here may potentially influence map outputs, however, given that their areal requirements are decided by the user (a tolerance value of 0 will force the model to find a location of each cell prescribed by the areal requirement) there is relatively little impact upon map outputs.

7.2 2050LOW scenario

To model 2050LOW land use map using new rank images

GIS ANALYSIS>DECISION SUPPORT>MOLA

Objective caption	Objective weight	Rank image	Areal requirements
Arable	6	*RANK536_31_loGS_arable*	411226
Pgrass	7	*RANK536_31_loGS_pgrass*	166294
Recre	5	*RANK536_31_loGS_recre*	25696
Roads	3	*RANK536_31_loGS_roads*	23836
Uncult	8	*RANK536_31_loGS_uncult*	199885
Urban	1	*RANK536_31_loGS_urban*	60490
Water	4	*RANK536_31_loGS_water*	60664
Wood	2	*RANK536_31_loGS_wood*	51881

Areal tolerance = 0
Output image = *lu536_31_2050LOW_NEWFINAL*

7.3. 2050hiRE scenario

To model 2050hiRE land use map using new rank images

GIS ANALYSIS>DECISION SUPPORT>MOLA

Objective caption	Objective weight	Rank image	Areal requirements
Arable	4	*RANK536_31_hiRE_arable*	607339
Pgrass	5	*RANK536_31_hiRE_pgrass*	11948
Recre	3	*RANK536_31_hiRE_recre*	25696
Roads	2	*RANK536_31_hiRE_roads*	23836
Uncult	8	*RANK536_31_hiRE_uncult*	199940
Urban	1	*RANK536_31_hiRE_urban*	38052
Water	6	*RANK536_31_hiRE_water*	60664
Wood	7	*RANK536_31_hiRE_wood*	32498

Areal tolerance = 0
Output image = *lu536_31_2050hiRE_NEWFINAL*

7.4. 2050HIGH scenario

To model 2050HIGH land use map using new rank images

GIS ANALYSIS>DECISION SUPPORT>MOLA

Objective caption	Objective weight	Rank image	Areal requirements
Arable	4	*RANK536_31_hiRE_arable*	604284
Pgrass	5	*RANK536_31_hiRE_pgrass*	15003
Recre	3	*RANK536_31_hiRE_recre*	25696
Roads	2	*RANK536_31_hiRE_roads*	23836
Uncult	8	*RANK536_31_hiRE_uncult*	199940
Urban	1	*RANK536_31_hiRE_urban*	38052
Water	6	*RANK536_31_hiRE_water*	60664
Wood	7	*RANK536_31_hiRE_wood*	32498

Areal tolerance = 0
Output image = *lu536_31_2050HIGH_NEWFINAL*

[Note: all areal values stored in TOTALCOVERAGES.xls]

8. Modelling 2100 scenarios (2100loGS run worked example)

To create transitional areas and probabilities files

GIS ANALYSIS>CHANGE / TIME SERIES>MARKOV
First (earlier) land cover image = *lu536_31_1995MMAP*
Second (later) land cover image = *lu536_31_2050loGS_NEWFINAL*
Prefix for output conditional probability images = *markov_loGS_536_31*
Number of time periods between first and second land cover images = 55 (i.e. 55 years)
Number of time periods to project forward from the second image = 50 (i.e. 50 years)
Background cell option = ASSIGN 0.0
Proportional error = 0

Repeat for all other scenarios.

All markov files:
markov_loGS_536_31
markov_LOW_536_31
markov_hiRE_536_31
markov_HIGH_536_31

To run CA_MARKOV to create 2100loGS land use map

GIS ANALYSIS>CHANGE / TIME SERIES>CA_MARKOV
Basis land cover image = *lu536_31_2050loGS_NEWFINAL*
Markov transition areas file = *markov_loGS_536_31transition_areas*
Transition suitability image collection = *markov_loGS_536_31*
Output land cover projection = *lu536_31_2100loGS_NEWF**
Number of cellular automata iterations = 50
Cellular Automata filter type = USER-DEFINED FILTER
Filter kernel file = *7x7*
Repeat for all other scenarios.

All unfiltered 2100 images:
lu536_31_2100loGS_NEWF
lu536_31_2100LOW_NEWF
lu536_31_2100hiRE_NEWF

lu536_31_2100HIGH_NEWF

To filter background noise from 2100loGS image

IMAGE PROCESSING>ENHANCEMENT>FILTER
Filter type = MODE
Filter kernel = 7x7
Input image = *lu536_31_2100loGS_NEWF*
Output = *lu536_31_2100loGS_NEWF_FILT7*

In IDRISI

To export final 2100 land use map to ArcMap format

FILE>EXPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select IDRISI TO ARCINFO RASTER ASCII FORMAT
Input file = *lu536_31_2100loGS_NEWF_FILT7*
Output file = *lu536_31_2100loGS_NEWF_FILT7* (with .asc extension)

In ArcMAP

To import land use map

ADD DATA>536_31> *lu536_31_2100loGS_NEWF_FILT7*
Right-click the new layer and select DATA>EXPORT DATA
FORMAT = GRID
Name = *lu31_00loGS_F* (limited to 13 characters)
Select SAVE
Choose to add layer to map

8.1. Erasing roads from land use image

This stage was required due to the cellular automata model (ca_markov) used to iterate between 2050 and 2100 time points, removing simple linear features, such as roads or water courses (i.e. a cell resolution of 5m^2 will remove features where they are less than the cell resolution). As these land covers were modelled such that there was no change in their spatial extent it was possible to erase these features from model outputs post-process and then to insert them back into the model. The next stage describes this process.

To convert from raster to features

SPATIAL ANALYST>CONVERT>RASTER TO FEATURES
Input raster = *lu31_00loGS_F*
Field = VALUE
Output geometry type = POLYGON
Output features = *lu31_00loGS_Fvec*

To erase roads from final vector land use image

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *lu31_00loGS_Fvec*
Erase features = *536_31roads*
Output feature class = *lu31_00loGS_Fvec_erase_rds*

To erase roads from 536_31 grid (to be later identified and reclassed as roads)

ANALYSIS TOOLS>OVERLAY>ERASE

Input features = *536_31*
Erase features = *lu31_00loGS_Fvec_erase_rds*
Output feature class = *lu31_00loGS_Fvec_erase_rdsfromgrid*

Open attribute table of *lu31_00loGS_Fvec_erase_rdsfromgrid*
OPTIONS>ADD FIELD
Name new field 'GRIDCODE', use LONG INTEGER
Delete 'ID', 'FID1' and 'FID2' fields
Right-click GRIDCODE field header>FIELD CALCULATOR
GRIDCODE = 444

8.2. To merge erased roads shapefile with erased roads vector land use image

To merge erased roads shapefile with erased roads vector land use image

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *lu31_00loGS_Fvec_erase_rdsfromgrid* and *lu31_00loGS_Fvec_erase_rds*
Output = *lu31_00loGS_Fvecroads*

To add additional roads (coded 444) to all other roads (land use code 4)

Open attribute table of *lu31_00loGS_Fvecroads*
OPTIONS>SELECT BY ATTRIBUTE
Create the following expression (Choose GET UNIQUE VALUES):
"GRIDCODE" = 444
Right-click GRIDCODE field header>FIELD CALCULATOR
GRIDCODE = 4

8.3. Erasing water from land use image

To erase water from the most up to date land use image (i.e. map with new roads)

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *lu31_00loGS_Fvecroads*
Erase features = *536_31water*
Output feature class = *lu31_00loGS_Fvec_erase_rdswtr*

To erase water from 522_24 grid (to be later identified and reclassed as water)

ANALYSIS TOOLS>OVERLAY>ERASE
Input features = *536_31*
Erase features = *lu31_00loGS_Fvec_erase_rdswtr*
Output feature class = *lu31_00loGS_Fvec_erase_rdswtrfromgrid*

Open attribute table of *lu31_00loGS_Fvec_erase_rdswtrfromgrid*
OPTIONS>ADD FIELD
Name new field 'GRIDCODE', use LONG INTEGER
Delete 'ID', 'FID1' and 'FID2' fields
Right-click GRIDCODE field header>FIELD CALCULATOR
GRIDCODE = 777

8.4. Merging erased water shapefile with erased water vector land use image

To merge erased water shapefile with erased water vector land use image

DATA MANAGEMENT TOOLS>GENERAL>MERGE
Input datasets = *lu31_00loGS_Fvec_erase_rdswtrfromgrid* and *lu31_00loGS_Fvec_erase_rdswtr*
Output = *lu31_00loGS_NEWCOMPLETE*

To change add additional water (coded 777) to all other water (land use code 7)

Open attribute table of *lu31_00loGS_NEWCOMPLETE*
OPTIONS>SELECT BY ATTRIBUTE
Create the following expression (Choose GET UNIQUE VALUES):
"GRIDCODE" = 777
Right-click GRIDCODE field header>FIELD CALCULATOR
GRIDCODE = 7

8.5. Converting final vector map to raster

To convert vector to raster

SPATIAL ANALYST>CONVERT>FEATURES TO RASTER
Input features = *lu31_00loGS_NEWCOMPLETE*
Field = GRIDCODE
Output cell size = 5
Output raster = *lu31_00loGS_C* (Saved in E:\Data\osmastermap\GRID\536_31)

8.6. Converting raster to ASCII for input into IDRISI

To convert raster to ASCII

CONVERSION TOOLS>FROM RASTER>RASTER TO ASCII
Input raster = *lu31_00loGS_C*
Output ASCII raster file = *lu31_00loGS_C* (with .asc extension)
(Saved in E:\Data\osmastermap\GRID\536_31)

8.7. Importing new layer into IDRISI

To import new layer into IDRISI

FILE>IMPORT>SOFTWARE-SPECIFIC FORMATS>ESRI FORMATS>ARCRASTER
Select ARCINFO RASTER ASCII FORMAT TO IDRISI
Input file = *lu31_00loGS_C.asc*
Output file = *lu536_31_2100loGS_NEWFINAL*
Repeat process for all other 2100 maps.

All final 2100 land use images:
lu536_31_2100loGS_NEWF
lu536_31_2100LOW_NEWF
lu536_31_2100hiRE_NEWF
lu536_31_2100HIGH_NEWF

All final land use maps for grid: lu536_31_1995MMAP

lu536_31_2050loGS_NEWFINAL	lu536_31_2100HIGH_NEWFINAL
lu536_31_2050LOW_NEWFINAL	lu536_31_2100hiRE_NEWFINAL
lu536_31_2050hiRE_NEWFINAL	lu536_31_2100LOW_NEWFINAL
lu536_31_2050HIGH_NEWFINAL	lu536_31_2100loGS_NEWFINAL

The processes described here were then repeated for each of the forty 5 x 5 km grid squares.