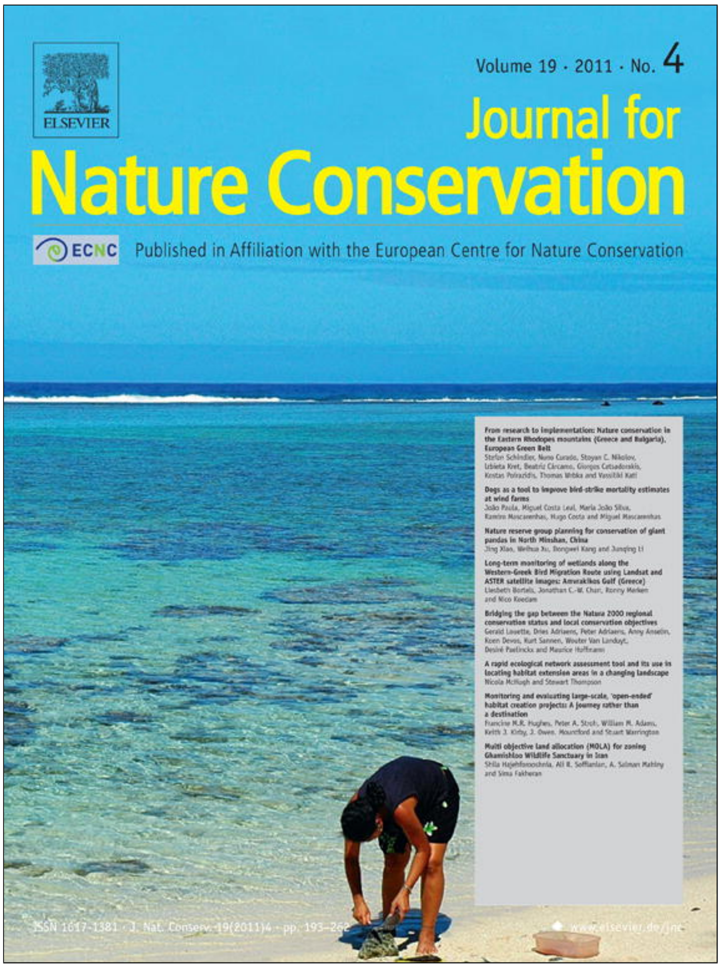

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Monitoring and evaluating large-scale, ‘open-ended’ habitat creation projects: A journey rather than a destination

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ABSTRACT

Ecological restoration frequently involves setting fixed species or habitat targets to be achieved by prescribed restoration activities or through natural processes. Where no reference systems exist for defining outcomes or where restoration is planned on a large spatial scale, a more ‘open-ended’ approach to defining outcomes may be appropriate. Such approaches require changes to the definition of goals and the design of monitoring and evaluation activities. We suggest that in open-ended projects restoration goals should be framed in terms of promoting natural processes, mobile landscape mosaics and improved ecosystem services. Monitoring can then focus on the biophysical processes that underpin the development of habitat mosaics and the provision of ecosystem services, on the way habitat mosaics change through time and on species that can indicate the changing landscape attributes of connectivity and scale. Stakeholder response should be monitored since an open-ended restoration approach is unusual and can encounter institutional and societal constraints. Evaluation should focus on reporting changing restoration impacts and benefits rather than on achieving a pre-defined concept of ecological success.

Introduction

Dominant approaches to ecological restoration typically aim either to re-establish the *status quo ante*, or to assemble specified or desirable habitats on degraded land (Jordan & Packard 1989). This may be achieved using established restoration engineering techniques or by allowing natural processes to do some of the work, for example, controlled floods in naturally dynamic habitats such as floodplains (Hughes & Rood 2003). In both cases there is an expectation that over a few years, particular species or habitat targets can be achieved based on predictable biophysical relationships. This approach is proven, and fits the desire of ecological managers, funders, spatial planners and local people to know what the outcomes will be. However, this prescriptive approach does not acknowledge the diverse and often novel starting conditions for much habitat restoration effort (Hughes et al. 2005; Hobbs et al. 2006; Seastedt et al. 2008; Zweig & Kitchens 2010). Over longer time periods it becomes both less effective and less appropriate to be prescriptive about restoration outcomes (Halle 2007; Hobbs 2007). Anthropogenic climate change may further limit the feasibility of restoring historic ecosystem states, and therefore the appropriateness of these as targets or reference conditions (Harris et al. 2006).

An alternative way to think about restoration is to view habitat development as ‘open-ended’, an ecological journey whose destination is uncertain rather than necessarily producing specific habitats or species populations (Hughes et al. 2008). In such situations, the restoration manager allows contemporary (and future) natural processes to dictate ecological outcomes rather than attempting to steer them to fit a pre-selected reference system. However, a restoration project conceived of in this way throws up a number of practical issues, such as how to frame the goals for the project, and how to monitor and evaluate change. In this paper we explore ways of both setting goals and designing monitoring and evaluation approaches for open-ended projects with particular reference to such a project in the UK.

Open-ended habitat creation projects

Open-ended restoration accepts and works with unpredictable ecological trajectories (‘forward-restoration’ *sensu* Halle 2007). This may be because the starting point is novel compared to most

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situations within which nature conservationists work, for example post-industrial sites or reclaimed land; or because there is no clear pre-defined ecosystem state that has to be achieved. Open-ended restoration may also reflect the recognition that there will be system shifts in environmental processes, for example due to climate change, and in the chaotic nature of interactions between them.

On the ground, open-ended projects emphasise low- or no-intervention restoration through the removal or reduction of human influence on both physical and biological processes, for example by allowing natural vegetation regeneration and succession rather than re-seeding. It is an approach that accepts habitats that develop on a site rather than prescribing and creating specific habitats. It does not recognise a 'correct state' for the restored system, because there is no *a priori* vision for the ecological outcomes. There is thus also little scope for adaptive management (*sensu* Murray & Marmorek 2003) since this would imply adjusting management to reduce uncertainty in the achievement of previously defined ecological outcomes.

The new ecosystem's trajectory into the future will be influenced by its ecological inheritance such as remnant seed banks, the influence of environmental filters and the proximity of land that can act as species sources. In many cases species-rich nature reserves that are legally protected and managed for defined species and habitats will act as one of the sources for species dispersal onto new restoration land. The new ecosystem may thus include novel species assemblages arising from species colonisation and extinctions that are an inherent consequence of the processes that have been initiated. The physical and biological processes involved may be in a constant state of flux and hence outcomes are transient at timescales of 10, 10^2 or 10^3 years (Fox 2007; Jentsch 2007). Outcomes most closely approach the 'future-natural' state for forest restoration described by Peterken (1996).

Application of the open-ended approach to restoration becomes more practical (and perhaps more desirable) as the spatial scale of restoration projects increases. In moving from small sites (scales of 10^1 and 10^2 ha) to larger sites (scales of 10^3 and 10^4 ha), there is more scope to adopt lower levels of management intervention and to depend more on available natural processes (Fig. 1). For example, the effects of coppicing in small woodlands may be achieved with natural rates of wind-blow in larger forests. As the spatial scale of a project increases, it is likely to encompass a wider range of biophysical conditions and so although the variability and uncertainty in project outcomes will increase (Hildebrand et al., 2005), the chances of any particular species finding a suitable habitat also increase. For example, in a small restoration site, an annual plant species dependent on seasonal wetland drawdown zones may appear briefly after the creation of a shallow water body but then disappear from the above ground vegetation due to rapid succession. However, if the restoration area is increased in size, more drawdown zones are likely to appear somewhere within the project boundary, allowing drawdown specialists more opportunities to germinate, flower and set seed in most years and consequently to persist in the area. At smaller spatial scales outcomes are likely to be limited by ecological processes, whereas at larger scales they are more likely to be limited by social or economic acceptability (for example, the views of local residents; Fig. 1).

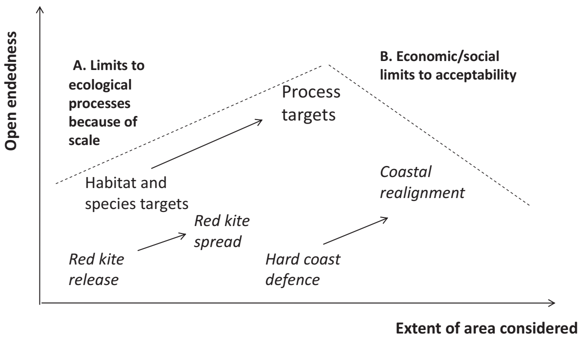

Fig. 1. Relationship between extent and the degree to which an open-ended approach can be used in habitat creation projects. In Sector A their use is limited by the site size; in Sector B economic and social factors put limits on their application. Two practical examples are noted in italics.

Setting goals for large-scale open-ended habitat creation projects

Where an open-ended approach to restoration is adopted, a logical main goal is to allow or enable natural processes to operate over a sufficiently large area that only low intensity or no management intervention is needed. A common implicit assumption in this approach is that there will be significant but unspecified local and regional biodiversity gains that will change through time in association with evolving habitat mosaics whose turnover rate will be related to the nature of the natural processes present. There is also an increasing implicit expectation that ecosystem services will arise from the ecosystem functions and habitats that develop. Development of a dynamic habitat mosaic and improved provision of ecosystem services thus become important secondary outcomes associated with the main goal.

Main Goal: Re-establishing natural processes over a large-scale

Allowing and enabling natural processes include facilitating fluxes of, for example, nutrients and water and the operation of disturbance processes over large, physically varied and functionally connected areas. The nature and scale of the relevant processes will vary with ecosystem. Thus for a wetland complex, the nature of the hydroperiod is an obvious and visible physical driver. In naturally regenerating woodland on former farmland, accumulation of litter, changes in light fluxes as canopies close and disturbances such as wind throw are relevant. Facilitation of natural processes might include what Manning et al. (2009) termed 'anticipatory restoration', where the efforts seek to create 'certain conditions in anticipation of further changes in the future'. For example, at the 'Wild Ennerdale' project in the north-west of England native trees have been planted at the top of a valley to provide seeds for eventual natural woodland regeneration elsewhere in the project area (Kirby et al. 2006). Larger scale reconnection of landscape pieces in order to anticipate future needs of species is also an example of anticipatory restoration and is one important objective of the Great Fen project in south-eastern England where two small but species-rich fenland nature reserves are being connected by purchase of 3500 ha of intervening arable land currently under conversion to new wetland habitats.

Open-ended projects are conceived of as 'long-term' with no imposed time limit, though for practical purposes they are typically framed in periods of time such as 50 or 100 years to make them conceptually both more accessible and acceptable to stakeholders. Many stakeholders will also need to see some short-term changes that they consider positive in order to maintain funding and support towards the project over longer periods, especially if vegetation takes a long time to adjust to a new landscape dynamic (for example, Tanentzap et al. 2010). Some forms of anticipatory restoration can be very useful for this purpose, for example small planted areas of trees can create visible changes in the landscape.

'Large-scale' must be defined in terms of a particular geographic and ecological context: a 'large' project in the context of southern England may be very different in size from one in the Amazon basin. Institutional factors are also relevant to the issue of scale: restoration in landscapes with large numbers of small landholders (for example in lowland UK) may be much more complex than landscapes where large tracts are held by a single owner (for example, a state agency). The appropriate scale for open-ended restoration should be informed by the need to try to include functionally coherent units such as stream catchments (Middleton 1999; Richter et al. 2003) or biodiverse areas (species 'hotspots') that can act as species sources. The scale will also determine the project area's ability to increase the connectivity of the landscape, for example for species that move within a biogeographic region or for migratory birds that move between continents. There may be additional biodiversity gains in being able to establish large core areas that provide ecological refuges or sanctuaries as suggested by the Vermejo vision for the North American bison (*Bison bison*) (Sanderson et al. 2008).

Subsidiary outcome 1: Development of dynamic habitat mosaics

In open-ended restoration, biodiversity gains are expected to arise from the creation of spatially varied and temporally dynamic habitat mosaics. Habitat turnover will be the result of the combined lag times between changes in biotic parameters and species response. Over time the nature and scale of relevant processes may also change. For example, in several large-scale wetland restoration projects in East Anglia, UK, catchment runoff and evapotranspiration rates determine water table depth and hydroperiod but over the next 50–100 years, sea-level rise may cause back-up of regional water tables and salt water incursion.

Development of dynamic habitat mosaics will involve both species losses and gains. This is an inevitable outcome where natural processes create disturbance at numerous spatio-temporal scales and initiate dynamic patterns of vegetation regeneration and succession across a site. At the outset some large-scale restoration projects, such as the Wicken Fen Vision project in the UK, were set up as buffer zones to struggling biodiversity hotspots where conserving diversity and rarity was a key aim. They therefore encompass areas with statutory protection and defined management practices for target conservation features and also areas where an open-ended approach to restoration may be promoted. While a dynamic habitat mosaic may benefit species previously confined to hotspots, other species may also move in. These might include not only species previously present that are able to re-colonise (for example, common cranes (*Grus grus*) have re-colonised parts of the Fens of East Anglia from the European mainland), but also 'new' species, perhaps in response to climate change. Challenges will arise if some of the species originally of concern start to decline, if the colonising species are 'invasive non-native species', or if there is perceived to be an overall decline in the diversity or quality of the species assemblages present. In such situations a decision may be taken to carry out more active conservation management within part of the project area to maintain critical species, while retaining the goal of reducing management intervention over the area as a whole.

There is likely to be less conflict between current and potential biodiversity aims if much of the project area starts from a low biodiversity base – the extreme case might be considered the large (6000 ha) reclaimed polder that has become the Oostvaardersplassen reserve in the Netherlands (Vera 2009). Here, any development under natural processes was likely to be positive. However, the disadvantage when all of the area has limited initial interest is that the rate at which richer habitats and mosaics develop may be slower than where there is at least a proportion of the area which includes species-rich existing habitats as sources. Even where natural processes, such as fire, destroy large tracts of habitat, vegetation communities may be able to rapidly re-assemble from nearby species-rich areas where the scale of the landscape allows these to remain intact. In Yellowstone National Park (USA), for example 250,000 ha of forest burnt in 1988, but post-fire species composition was found to be more determined by location within the landscape and previous vegetation history than by the size of individual areas burnt (Turner et al. 1997).

Subsidiary outcome 2: Improved provision of ecosystem services (ESS)

The capacity of restored ecosystems to deliver ecosystem services in a cost-effective way may become an important element in their attractiveness to planners (Daily et al. 2009; Millennium Ecosystem Assessment 2005; Naidoo et al., 2008). While all ecosystems have the potential to deliver services, there is a limit to multi-functionality of landscapes, and trade-offs between services are often inevitable (Eigenbrod et al., 2009). Demonstration of net ecosystem service benefits (or the likelihood of their future delivery) is particularly important where the project involves direct or opportunity costs in terms of the obvious provisioning services, for example, through the inevitable reduction in food or fibre production when intensively farmed arable land is converted to semi-natural habitat. Open-ended restoration projects that enhance or support the functioning of biophysical processes over large areas may have a role to play in delivering services. Thus a project encouraging woodland succession would contribute to carbon sequestration and storage, while a formerly drained wetland allowed to flood again could contribute to flood defence or improved water quality or quantity. Economic arguments about the value of services provided by the open-ended approach need also to be set alongside the intrinsic values of more natural systems if they are not to be construed as constraints on an open-ended approach (see also Redford & Adams 2009).

In open-ended restoration projects, improved ecosystem services are likely to depend on improved ecosystem function (e.g. Soini et al., 2010), including basic natural processes such as the movement of nutrients and water and related processes such as vegetation succession. These ecosystem functions are in turn related to increased landscape connectivity across large areas. Large, open-ended restoration projects may provide a novel suite of ecosystem services through the interaction of processes at a range of spatial scales. In some cases, these projects involve extensive engagement with stakeholders whose perception of the benefits of ecosystem services is to a great extent socially and economically determined (Dufour and Piegay, 2009). As a result, stakeholder participation in planning can have some influence on the suite of services provided. This has taken place at the Wicken Fen Vision project in the UK, where stakeholders have had considerable input to the provision of recreational services. It thus becomes important to discuss at an early stage in a landscape-scale restoration project, the extent to which enhancing ecosystem services will be a main driver of restoration or a by-product of restoration that has been carried out to enhance landscape resilience for biodiversity.

Monitoring large-scale, open-ended habitat creation projects

Monitoring and evaluation are considered necessary for effective biodiversity conservation and restoration (Knight et al., 2006; Kapos et al., 2008; Margules & Pressey 2000). Many conservation professionals and local people expect that habitat and species outcomes should be predictable and within agreed limits. Monitoring often thus focuses just on these features and restoration projects are expected to show 'value for money' as conservation investments by showing progress towards these pre-set targets. This becomes difficult if the 'outcome' in habitat or species population terms is open-ended or undefined (and indefinable) and may not, because it is novel, have a pre-existing conservation value. In an

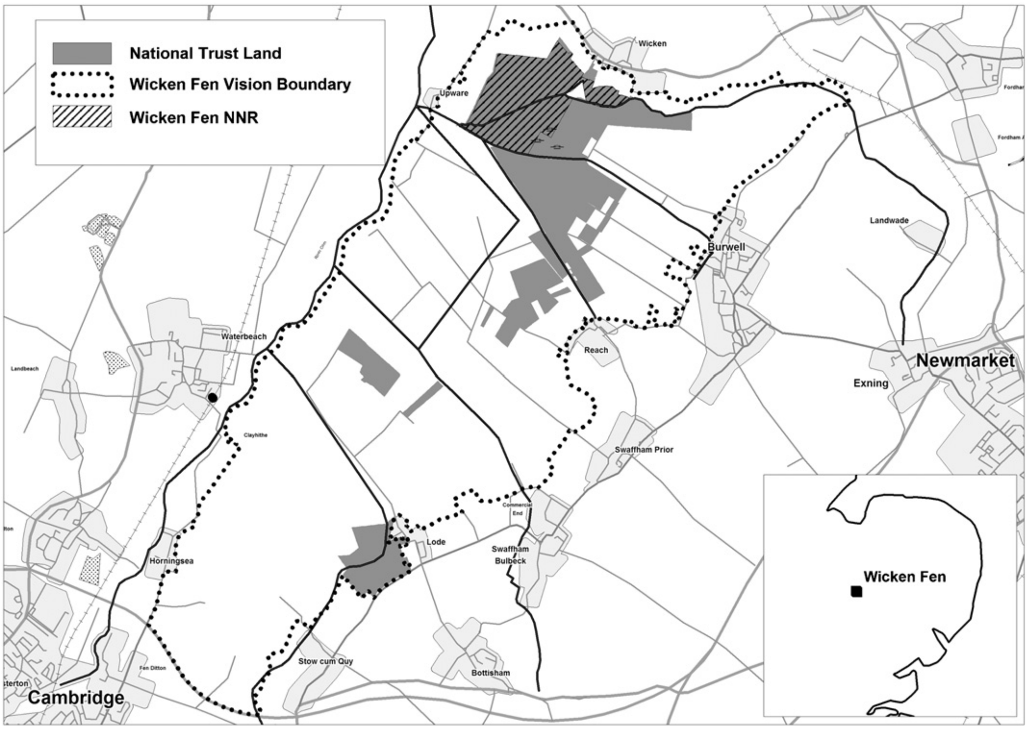

Fig. 2. Map of the Wicken Fen Vision project in East Anglia, United Kingdom.

open-ended restoration project, therefore, it becomes as important to monitor the processes that drive system function as it is to monitor the state of any habitat or species. Measuring ecosystem function can also indicate the capacity of the project to contribute to ecosystem service provision (Benayas et al., 2009). However, monitoring ecosystem function is not limited to open-ended projects as such measures may also be included in the monitoring of sites with more prescriptive management approaches. For example, elements of ecosystem function monitoring are included in the UK's Common Standards Monitoring process for Sites of Special Scientific Interest (SSSIs).

Since it is not clear which features or species may be viewed as important in future the initial baseline from which change is assessed needs to be broad; a 'status assessment' which is the systematic documentation over time of particular conservation features (for example, species or habitats) (Stem et al. 2005). Status assessment may be criticised as time consuming and inefficient (Nichols & Williams 2006), productive of unwieldy levels of data, prone to inconsistency over time and rarely able to relate cause to effect (Lindenmayer & Likens, 2010). Nevertheless, for open-ended projects a status assessment approach is appropriate, because there are no specific *a priori* targets for biodiversity outcomes or for exactly how interactions between physical and biological elements of the ecosystem will evolve. A status assessment approach allows a wide range of questions to be addressed subsequently through the data, by making an initial, broad choice of parameters that reflect developing biophysical relationships. This is well demonstrated by the monitoring programme set up at the Knepp Castle Estate's Wildland Project in Sussex, UK where 3500 ha of land have been taken out of arable production and put under a naturalistic grazing regime. Here a status assessment approach to monitoring serves to assess the deviation of habitats away from arable as a result of the implementation of a low-intensity naturalistic grazing regime using cattle, ponies, pigs and deer (Greenaway, 2009).

The monitoring of open-ended projects is potentially complex to design and deliver and itself potentially open-ended in terms of cost. We use our own experience of setting up a monitoring programme at an open-ended, large-scale project in lowland England, the Wicken Fen Vision, to explore ways of doing this.

Background to the Wicken Fen Vision

Wicken Fen National Nature Reserve (NNR), owned by the National Trust, consists of 170 ha of alkaline fen and is a highly species-rich (>8000 species) wetland and a designated Ramsar site (The Convention on Wetlands of International Importance, 1971) in the fenlands of East Anglia, UK. It is intensively managed in order to conserve current diversity and comply with conservation legislation (Mountford et al., 2005) and is monitored using the UK's Common Standards Monitoring protocols (Williams 2006) for protected sites. In 1999 the Wicken Fen Vision was launched, a landscape-scale habitat creation project with a stated 100-year time frame (Colston and Friday, 1999; Colston, 2003) over which it would acquire 5300 ha of drained and intensively farmed arable land between the NNR and the city of Cambridge to the south-west (Fig. 2). The Wicken Fen Vision's initial aim was to improve the sustainability of the species-rich NNR but it acquired its own dynamic partly because large-scale, less prescribed approaches to conservation were moving onto the British conservation agenda and partly as a response to the understanding that having access to whole hydrological catchments offered a more sustainable approach to creating wetland habitats. The project grew into a large-scale open-ended project with a main goal of creating a dynamic wetland landscape characterised by mobile vegetation mosaics and shaped by low-intensity management using herds of self-reliant large herbivores (Konik ponies and Highland cattle), fluctuating water tables and natural regeneration. To date the reserve has grown to a size of 930 ha of which currently 390 ha are managed using an open-ended restoration approach. Even so this area is subject to constraints such as the total amount of water available, legislation regarding the control of designated noxious weeds, animal welfare requirements and the attitudes of residents in local villages. There are no analogues to inform expectations of ecological outcomes at the site (Hughes et al. 2005). It did not seem appropriate or practical to simply scale

Table 1
Analysis of biophysical conditions: current situation and future constraints at the Wicken Fen Vision.

Process	Current	Direction and future constraints
Water level fluctuations.	Managed at field level (field drains are blocked to allow water tables to rise; additional water is added when winter water is available).	*No management within site, seasonal variations expected with winter highs and summer lows.* Flows into and out of site to be agreed with neighbours through the Internal Drainage Board. Water quantity limits in the catchment (both due to expected reduced rainfall and increased water demand for other purposes) and artificial land levels will prevent many areas from becoming wetland.
Grazing and browsing by large herbivores.	Introduced semi-feral ponies and cattle + roe deer, red deer and muntjac deer that have arrived on their own.	*Semi-feral herds to be self-regulating.* Surveillance of numbers and behaviour of animals required to comply with welfare standards.
Natural regeneration and succession.	Dry grassland with scrub, dominated by hawthorn (*Crataegus monogyna*), in some areas, wet grasslands and other wetland habitats elsewhere.	*Dynamic habitat mosaic including both terrestrial and wetland habitats.* Grazing, browsing and elevated water tables are expected to limit areas reaching upper successional limit but water quantity limits in the catchment (due to both expected reduced rainfall and increased water demand for other purposes) and artificial land levels will prevent many areas from becoming wetland.

up the targets that had been set for the National Nature Reserve to the much larger Vision area.

Monitoring the Main Goal: Re-establishing natural processes over a large-scale

When monitoring of the Wicken Fen Vision was initiated in 2007 the first step was to undertake an analysis of the main current and expected biophysical processes across the area, the desired direction of change and any future limits on these processes (Table 1). Monitoring of hydrological processes, of grazing and browsing by large herbivores and of natural regeneration and succession were identified as a high priority.

The hydrological monitoring currently set up at the Wicken Vision includes automated water-table and rainfall monitoring and manual ditch level and soil moisture monitoring. This is to track change both in the potential water budget across the site and in characteristics of the hydroperiod of the site. Grazing exclosures have been set up in order to track the impacts of grazing and browsing across the site using fixed quadrat locations both inside and outside the exclosures. The regeneration potential of the seed bank has been studied to understand better its role in determining habitat development through natural regeneration (Stroh et al. 2010). Studies are also underway on the role of the grazing animals as vectors of seed dispersal.

The other part of the main goal is that the natural processes listed above should be established over a large scale, primarily across the designated Wicken Vision area but with potential effects beyond its boundaries. It is expected that there will be new connections formed through and between different landscape elements for species that might not otherwise be able to move around or use the landscape. This has led to the idea that monitoring of chosen species can be used to tell project managers about the status of this wider landscape rather than the conventional approach which monitors a species in order to tell managers about the species' own status on their particular nature reserve. Thus species groups have been chosen for monitoring that can give information about specific landscape attributes including: (i) the effective size of the restoration area; (ii) the bridging of landscape gaps; and (iii) the environmental quality of the restoration area (Table 2).

The restoration project will have been effective as a 'large-scale project' if it attracts focal landscape species (Didier et al. 2009; Wildlife Conservation Society 2001) that require a minimum sized range and a variety of habitats. Some of these species, for example, browsing animals such as roe deer (*Capreolus capreolus*) which have become resident in the project area, are themselves acting as vectors of habitat change. Other species may be indicative of landscape connectivity, for example those that depend on functionally coherent and physically linked units such as migratory fish or mammals such as water voles (*Arvicola terrestris*) and others that can use stepping stones or that are part of a metapopulation structure (Amezaga et al. 2002). Hence, small mammals, roe deer, wintering and breeding birds and bats are all being surveyed. Some of these species may also be monitored in more prescriptive restoration projects, but in such cases they are more likely to be the target species of the restoration work. Use will also be made of the long-standing bird-ringing programme (>40 years) on the site which can provide information on fluctuations in occurrence and abundance of some species.

Different species groups can act as markers for environmental change, for example fish (Mann 1996) or macroinvertebrates (Friberg et al., 1998). At the Wicken Fen Vision, invertebrate species (both aquatic and terrestrial) are being monitored as a proxy for ecological quality of new wetland habitats forming within ex-arable land. However, it is important to recognise that there can be lags between environmental quality change and species use of an area, and some species will not be able to appear before water quality improves. In some regards, this monitoring has parallels with requirements for monitoring ecological quality of water bodies under the European Water Framework Directive (E.U. Directive 2000/60/EC) and implementation of this Directive has greatly enhanced the range of methods available (for example Logan & Furse 2002).

A monitoring approach that uses species to provide information about landscape attributes and how they change over time, rather than monitoring against pre-determined species targets represents a different direction for UK conservation practice. Ideally the results of this approach at Wicken Fen would be compared with those from other large-scale wetland restoration projects that use a more traditional, target-led approach. One possibility is the wetland restoration project at Lakenheath, in East Anglia, UK, managed by the Royal Society for the Protection of Birds (RSPB). Just as important is a comparison with equivalent sized, un-restored areas in the wider countryside and it is hoped that the monitoring project data will be linked into other national studies by standardising some of the monitoring protocols with the UK's Countryside

Table 2
Monitoring activities associated with the main goal of open-ended restoration at the Wicken Fen Vision, UK.

Main Goal: Re-establishing natural processes over large spatial scale	
Monitoring activities	Expected changes relative to starting point (impacts or benefits)
Continuous or monthly measurement of hydrological variables including: • Water tables • Soil moisture • Soil matric potential (suction) • Ditch levels	• Higher average water tables • More seasonally varied water tables • Extensive seasonally wet areas
Annual counts and observation of Grazing/browsing animal numbers and behaviour • Introduced Konik ponies • Introduced highland cattle • Roe deer	• Over 100 self-reliant grazing animals, most born at the Wicken Fen Vision • Development of herd behaviour • Resident and growing herd of roe deer
Annual counts of 'landscape species' gives information on presence and population size	• Breeding of 'landscape species', e.g. raptor species and roe deer • Overwintering of 'landscape species', e.g. migratory birds • Visiting by landscape species ('stepping stones'), e.g. red deer
Annual surveys of 'environmental indicator species' • Aquatic macrophytes in ditch systems. • Extensive invertebrate survey method designed for large-scale Fen projects	• Higher species diversity
Annual surveys that might locate 'hotspot' species • Animal or plant species previously confined to Wicken Fen NNR	• Extensive invertebrate survey technique has picked up species likely to have been previously confined to Wicken Fen NNR, e.g. *Cerapheles terminatus*. Future surveys will allow better assessment of change
Annual surveys that might locate species that have bridged a landscape 'gap' at regional scale, e.g. dragonfly or butterfly	• Presence of e.g. butterfly species not previously present
5-yearly surveys of vegetation regeneration and succession (see also subsidiary outcome)	• Novel wetland and drier habitat types associated with different edaphic conditions and past land use histories. Some may resemble habitats described in the UK National Vegetation Classification system

Survey (Carey et al. 2008; Smart et al. 2003), which has taken place on an approximately 7-yearly cycle.

Monitoring subsidiary outcome 1: Development of dynamic habitat mosaics

Whereas much conservation in the UK frequently aims to hold vegetation communities at a particular successional stage, open-ended restoration practice expects to create heterogeneous and changing vegetation mosaics. (It is conceivable that landscapes could become more uniform, but, while unlikely, that should also be an acceptable outcome.) The aim of monitoring habitat mosaics is to understand how heterogeneous the landscape is at one point in time and then to track how rapidly the habitat mosaic turns over through time (changes in extent of different types, patch size and distribution). Remote-sensing techniques have greatly simplified this area of work.

At the Wicken Fen Vision we have used False Colour Infra Red (FCIR) aerial photomosaics at a scale of 1:7000 and both fixed and randomly located vegetation quadrats to produce a habitat change protocol, based on an image segmentation technique that will be repeated on a five-yearly cycle. An alternative technique has also been tested involving an 'object-based' interpretation of FCIR images that combines the objectivity of 'unsupervised' classification of pixels with supervised classification using field data and mapping (Smith et al. 2010). Both techniques have been carried out on images from 2007 and will be repeated in 2012. Turnover rates, fragmentation indices and edge to centre ratios for habitat patches are being used to describe the vegetation mosaic (Table 3).

Monitoring subsidiary outcome 2: Improved provision of ecosystem services

Delivery of ecosystem services is increasingly used as part of the justification for biodiversity conservation. While there are an increasing number of GIS-based analyses of ecosystem service provision at global or regional scales (for example, Eigenbrod et al., 2009; Naidoo et al., 2008; Nelson et al. 2009), there are few examples at the local or project scale. Some services such as above-ground carbon in forests can be straightforward to measure but others such as aquifer recharge and carbon conservation or capture are more intractable. All measures need to allow for possible step changes rather than linear changes in future service provision (Koch et al. 2009) and for the identification of direct and indirect beneficiaries, for example local recreational use of the Wicken Fen Vision versus the indirect benefits for National Trust members of the existence of the project.

An important practical question is what services are likely to have a significant effect and which of these can be assessed in a meaningful (preferably quantifiable) way? The two services that appear to offer most potential are flood storage and recreation (Table 3):

1. Flood storage can create a safer environment for local communities in an age of increased flood risk. Part of the Wicken Fen Vision area is a flood storage zone, designated by the UK's Environment Agency. Monitoring of water tables and soil moisture in the project area will contribute to the calculation of flood-holding capacity.
2. Recreational use is usually under-represented in assessments of ecosystem services in conservation projects (Eigenbrod et al., 2009). The open access policy over much of the Wicken Fen Vision area makes assessment of total recreational use difficult (visitor numbers to Wicken Fen NNR range between 40,000 and 50,000 per year and many more visit the Wicken Vision area), but visitor surveys have shown that the primary reasons for visits to the area are to watch wildlife and to get 'peace and quiet' (National Trust 2009).

The carbon loss avoided by conserving and eventually reversing the ongoing degradation of remnant peat soils in the Wicken Fen Vision area is also an important ecosystem service. Measurement

Table 3
Monitoring activities associated with the two subsidiary outcomes of open-ended restoration at the Wicken Fen Vision, UK.

	Monitoring activities	Expected changes relative to starting point (impacts or benefits)
Subsidiary outcome 1: Development of dynamic habitat mosaic	Production of maps of vegetation assemblages using FCIR aerial photomosaic taken in 2007. Next aerial survey 2012 • 'Object-based' analysis combined with supervised classification • Image segmentation technique	• Novel wetland and drier habitat types associated with different edaphic conditions and past land use histories
	Design of indices to describe mosaic change: • Pixel turnover rates • Fragmentation • Edge to centre ratios	• Movement of vegetation assemblages but also changes in composition of vegetation assemblages
	Survey of fixed vegetation quadrats (2 m × 2 m) at 5-yearly intervals	• Novel wetland and drier habitat types associated with different edaphic conditions and past land use histories.
Subsidiary outcome 2: Improved provision of ecosystem services (ESS)	Automated measurement of carbon flux	• Increased carbon conservation and capture
	Automated continuous monitoring of water tables	• Increased ground water recharge
	Annual Monitoring of species indicative of water quality, e.g. aquatic macrophytes	• Improved water quality
	Annual measurement of non-timber natural products, e.g. *Cladium mariscus* used for thatching rooves of houses	• No change as currently confined to NNR
	Monitoring of various recreational uses, e.g. number of angling licences, dog-walkers, other visitors, engagement with conservation activities	• Increased opportunities for recreational and aesthetic activities
	Annual monitoring of species arrivals and departures over time	• Changing species diversity

and analysis of carbon flux values at Wicken Fen are currently being made (Morrison pers. comm.).

Negative effects of restoration on other services could also be recognised and assessed, notably the implications for food provision of converting arable land to land used for habitat restoration. Any continuing food production, e.g. from extensively grazed livestock, is likely to be marginal by comparison at present. However not all of the potential arable land is currently used for food production: 22% is used to produce non-food products such as flowers and garden turf or for keeping horses (Cook 2009). The long-term sustainability of the current arable farming systems may also be uncertain. In the Wicken Fen Vision area much of the land is reaching a point where it will no longer be classified as Grade A agricultural land (high quality under UK classification system) because the remnant drained peat is now very shallow over the underlying and less productive clay soils.

The timing and funding of monitoring

In most projects there is tension between using resources to carry out restoration work and diverting some of these towards monitoring what the restoration is achieving. Monitoring is notoriously under-funded as an activity, but in a monitoring programme that stretches over many decades some elements can afford to take place at infrequent intervals (for example, measurement of habitat mosaic attributes using remote-sensing can take place every 5–10 years) while other areas of monitoring (for example, numerous species groups) need to be undertaken yearly. Involvement of volunteers can be a way of reducing costs and also of securing greater involvement from local communities but in order to keep volunteers engaged they need to be involved in the monitoring activities that take place on a yearly basis. At an open-ended, large-scale project like the Wicken Vision, many species groups need to be monitored in order to build up the picture of landscape attributes described above, and thus designing monitoring protocols that are simple and robust is essential for use where the particular volunteers working at a site may differ from year to year. Some tasks, however need to be undertaken by scientists with specialist knowledge and the frequency of monitoring of these tasks will to some degree be dependent on available funding. At Wicken Fen, many of these tasks (for example, monitoring of fixed and random vegetation quadrats, and analysis of hydrological data) have been placed on a 5-yearly monitoring cycle (Stroh & Hughes 2010).

At many conservation sites engagement of volunteers in the monitoring process either alongside or instead of conservation professionals has met with variable success (Danielsen et al. 2005; Danielsen et al. 2008). There is evidence that volunteer based schemes can provide relatively reliable data (Schmeller 2008) and improve citizen engagement and environmental awareness (Bell et al. 2008). The volunteers currently working at the Wicken Vision Project (around 40 in number in 2010) are from the local area and span a great range of backgrounds in terms of prior monitoring skills, but through the monitoring programme they have all been trained in monitoring protocols and species identification.

Evaluating open-ended habitat creation projects

Open-ended approaches do not lend themselves to conservation evaluation methods established in the UK that rely on an image of success defined by specified species or habitats. Instead success can be understood as the operation of dynamic and changing biophysical processes across a restoration area. Restoration projects that are explicitly open-ended are to date uncommon and many in the conservation movement are uncertain as to their value. Therefore, evaluation at a variety of levels can be useful in creating a positive attitude towards the project from a wide range of potentially sceptical stakeholders.

If a project's starting point is ecologically exceedingly impoverished, highly variable biodiversity gains can be expected as a result of species immigration and emigration through time, and may be particularly marked in the first decades of the project. For example, while birds may rapidly discover areas of newly formed marginal wetland, it may take a lot longer to acquire the diverse soil invertebrate fauna (Riggins et al. 2009) on which these bird species rely over the long term. Evaluation must therefore be planned as a long-term process, rather than something designed to serve short-term management decisions.

Our experience at the Wicken Fen Vision suggests that the emphasis should be on reporting about benefits in different ways to different, identified stakeholder groups (for example, Reed 2005). Benefits may come in terms of ecosystem services (carbon, or a cultural sense of 'wildness' (Taylor 2005)) or in terms of species whose range or population levels have increased (for example, some landscape species) or in terms of new landscape connections at different spatial scales (for example, local or regional). For many stakeholders, benefits measured in terms of ecosystem services will be more interesting than those measured in terms of biodiversity. Working out who wants to know about which benefits can help direct use of monitoring resources.

Conclusions

Open-ended, large-scale restoration projects emphasise the importance of natural processes and are characterised by uncertain outcomes. Many stakeholders find them difficult to engage with as they represent a departure from the conventional conservation philosophy of *limiting* ecosystem change to deliver tightly defined conservation objectives. The long time-frames also present a challenge. Monitoring of open-ended projects thus becomes a very important activity for three main reasons:

1. Open-ended restoration is a largely exploratory approach leading to unpredictable conservation outcomes, and hence these need to be monitored over long periods of time. While projects should contribute to ecosystem resilience by offering more long-term options for wildlife under a changing climate (Elmqvist et al. 2003), this cannot yet be shown.
2. Sceptical stakeholders can see that project managers are concerned about the outcomes and are keeping track of new processes that may appear threatening to them. The novelty of such projects suggests that close monitoring of social dimensions of the project would also be valuable (Wilder & Walpole 2008).
3. Some of the benefits of an open-ended approach can be measured and used to explain the value of the project with a variety of decision-makers.

Many ecological restoration projects are to some extent open-ended, if only because of the inherent uncertainties of future climate change. Conventional 'target' based goals are unlikely to be appropriate for such projects. In this paper we have considered possible goals for open-ended restoration projects, and the associated challenges of monitoring and evaluation.

The arguments made in this article about open-endedness also apply in part to established nature reserves, where known and valued habitats are likely to change over time in response to anthropogenic climate change, isolation, the arrival of exotic species and other forces. Current management might have to be relaxed over time since the cost of arresting anthropogenic change may become prohibitive. A measure of open-ended 'heuristic' thinking may be useful, although the balance of gains and losses will be very different between such sites and new sites with little established conservation value.

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