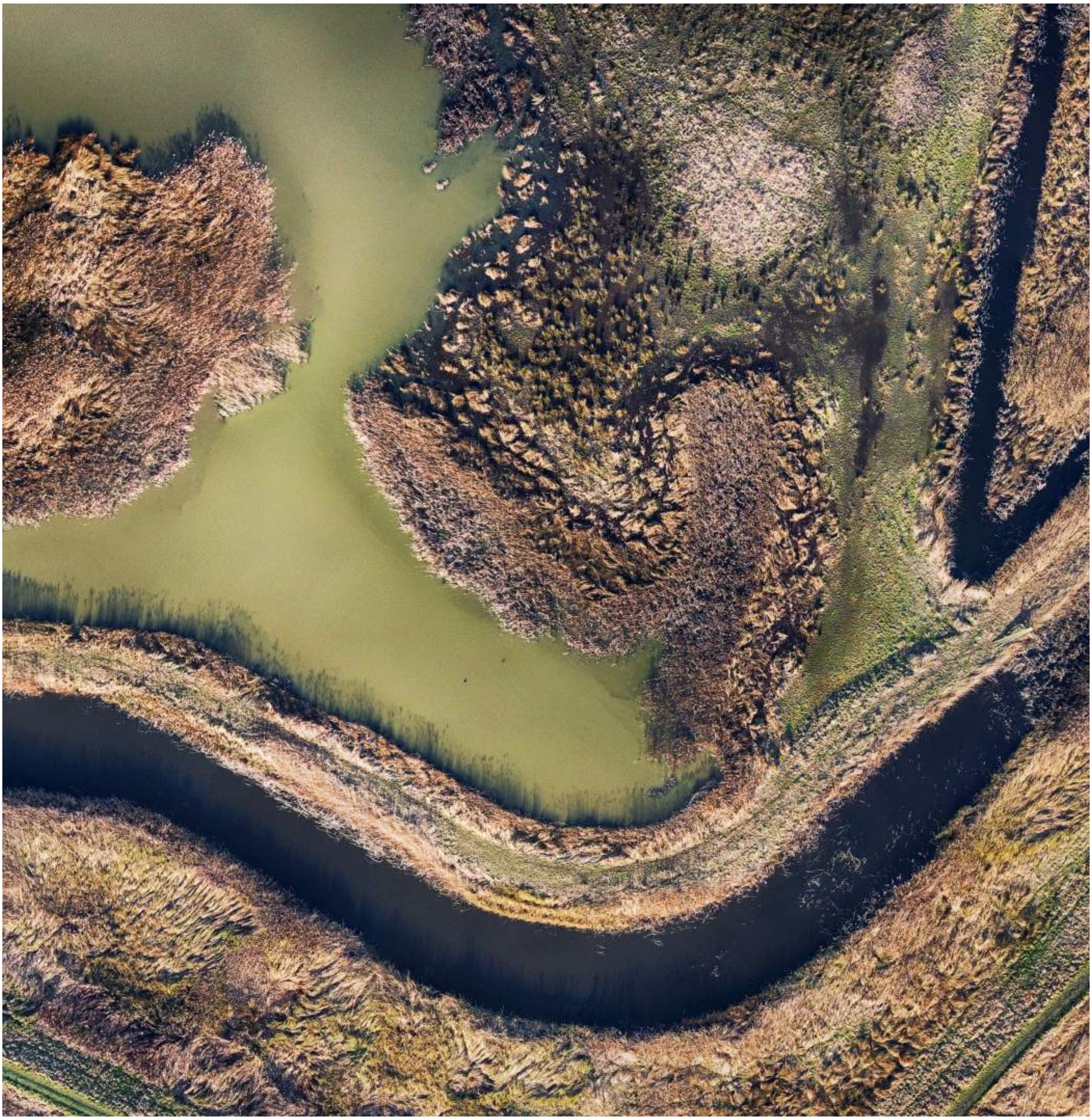
2017 Broads Authority Report

Development of Fen Monitoring, Research and Management

Report 2

Key Topics for Research - Evidence Review



Broads Authority

The study is a Broads Authority and Natural England initiative, undertaken by Mike Harding, funded by the Broads Authority and Natural England.

Project Manager

Andrea Kelly, Broads Authority - Senior Ecologist

Acknowledgements

We are grateful to the following people who helped us with this project:

- Members of the project steering committee:
- Broads Authority: Andrea Kelly, Erica Murray, Sue Stephenson
- Natural England: Alex Prendergast

Citation

Harding, M. (2017) Development of Fen Monitoring, Research and Management in the Broads. Report 2 - Key Topics for Research - Evidence Review. Report for Broads Authority, Norwich and Natural England

Published by

Broads Authority

NATURAL ENGLAND

Broads Authority

Terms and Conditions for use of maps in this document

i) You are granted a non-exclusive, royalty free, revocable licence solely to view the licensed data for non-commercial purposes for the period during which the Broads Authority makes it available. ii) You are not permitted to copy, sub licence, distribute, sell or otherwise make available the Licensed Data to third parties in any form iii) Third party rights to enforce the terms of this licence shall be reserved to Ordnance Survey

CONTENTS

SUMMARY

This report forms part of a series of reports examining monitoring, research and management of the Broadland fens. The current report reviews gaps in our understanding of fen ecology related to management which are impeding progress with managing Broadland fens. This review will then inform a seminar to develop research priorities for future funding.

The report is organised by Themes containing inter-related research topics. In the 12 years since this exercise was last undertaken, few if any of the research priorities identified in Harding (2005) and in subsequent workshops have been addressed. Meanwhile, site managers continue to progress new management initiatives or maintain old prescriptions without certain knowledge that the selected management will be appropriate to the sites. There is a clear risk in applying management regimes – especially novel ones or those with little historic context – without an underpinning of sound science. A key outcome of the research is to minimise such risk and increase certainty of site management. The thirteen themes are:

- Data Management and Coordination
- Long Term Change in Fen Vegetation
- The Economic and Social Sustainability of Fens
- Fen Hydrochemistry
- Hydrological Connectedness
- Managing the Hydroseral Succession
- Re-creating Rare, Complex, Species-rich or Distinctive Fen Vegetation
- Acidification of Fens
- Fen Grazing and Animal-Plant Interactions
- Fen Cutting
- Gathering the Knowledge: What is Known and What is Not
- Arisings from Fen Management
- Methodology for Science Work

Funding opportunities are reviewed. They are grouped into Partner Funded and Major Research Funds. The advantages and disadvantages of each are discussed. While funding is tight, it is not impossible if universities and researchers can be enthused and engaged.

For each theme, specific research questions are outlined. Undertaking even a proportion of this research would result in a step change in conservation practise in the Broads. It would allow the conservation sector to emerge from a period of practise informed by experience and anecdotal evidence, to a period of much greater certainty underpinned by sound science.

Considerable challenges exist in renewing the science effort. However, if these challenges can be overcome, Broadland conservation will move to a new level.

1. INTRODUCTION

The purpose of this report is to review gaps in our understanding of fen ecology related to management which are impeding progress with managing Broadland fens.

The report is organised by Themes, which include inter-related research topics. There are no hard boundaries to the Themes, some being interlinked.

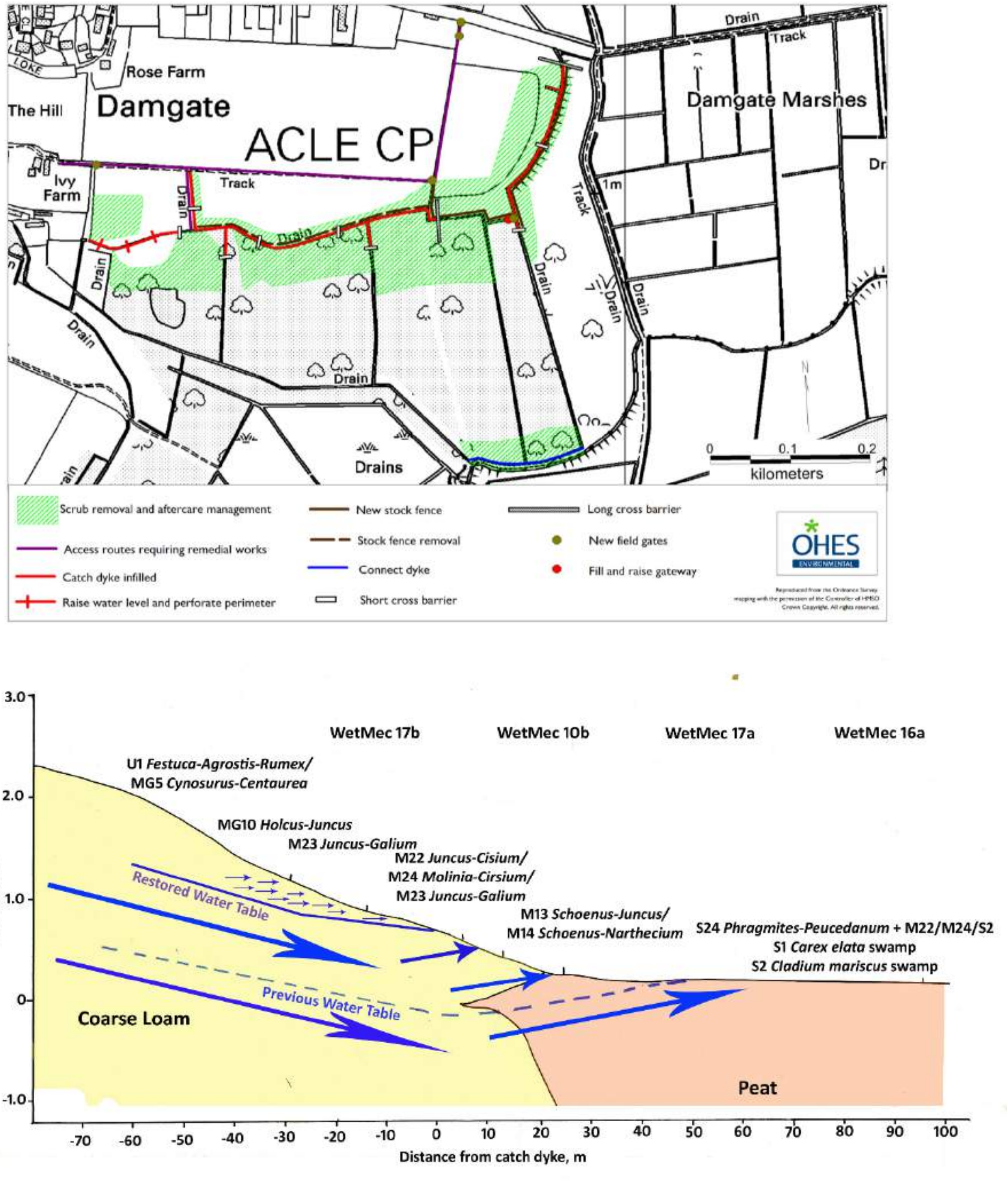
This review will then inform a seminar to develop research priorities for future funding.

It is not intended to be a literature review of fen ecology. It will make use of previous reviews of literature, together with grey literature. Sources of information used include some of the review reports (ELP 2010, OHES 2014, 2016a.b, Harding 2005, Wheeler et al 2009, McBride et al 2011) together with a plethora of Broads Authority file notes and the notes of the Fen Workshops 2015, 2010.

2. RISK

Although understanding of fen community ecology and the impacts/benefits of site management have increased over the last 30 years (for example in relation to catch dykes, Figure 1), there are still significant gaps in our understanding that limit our ability to create, restore or manage sustainably the fen resource. In the 12 years since this exercise was last undertaken, few if any of the research priorities identified in Harding (2005) and in subsequent workshops have been addressed.

Figure 1 : Restoration of Catchdykes at Decoy Marshes Acle, with Suggested Recovery of Valley Margin Plant Communities. OHES 2016a.



Meanwhile, site managers continue to progress new management initiatives (Figure 1) or maintain old prescriptions without certain knowledge that the selected management will be appropriate to the sites. This is sometimes a necessity – “paralysis by analysis” can be as much a threat to a site as any selected management. However, there is a clear risk in applying management regimes – especially novel ones or those with little historic context – without an underpinning of sound science.

A key outcome of the research is to minimise such risk and increase certainty of site management.

3. SCOPE

The focus here is on Broadland fens. These are principally floodplain fens. However, Broadland past may have been a much more complex ecosystem with a stronger component of groundwater fed fens, base poor fens and even wet heaths. These have been lost mostly as a consequence of the truncation of the dryland end of the wetland sequence. Valley margin habitats are likely to have included seepage areas and soligenous mire of variable water chemistry. Their restoration and management is seen as increasingly important in Broadland (Figure 1). The literature and management practises associated with soligenous fens is therefore included.

The scope does not include aquatic habitats such as broads and dykes. However, it does include the hydroseral succession from open water through swamp to fen as this succession includes some of the richest, rarest and most dynamic of Broadland fen communities. Fen carr and mature woodland is not included.

4. Themes For Research

4.1 Data Management and Coordination

A consistent theme of the Fen Workshops and other discussions is the lack of central coordination for research and monitoring efforts (Figure 2), for data collection and storage, data analysis and dissemination of results.

Figure 2: Coring in Fens. Coordinating collection and analysis of hydrological and ecological data is a key task.

Many of the research projects described below will involve multiple partners and a range of site ownerships. Strong central management of the whole process will be required if projects are to be delivered successfully. The longer-term the project, the greater the importance.

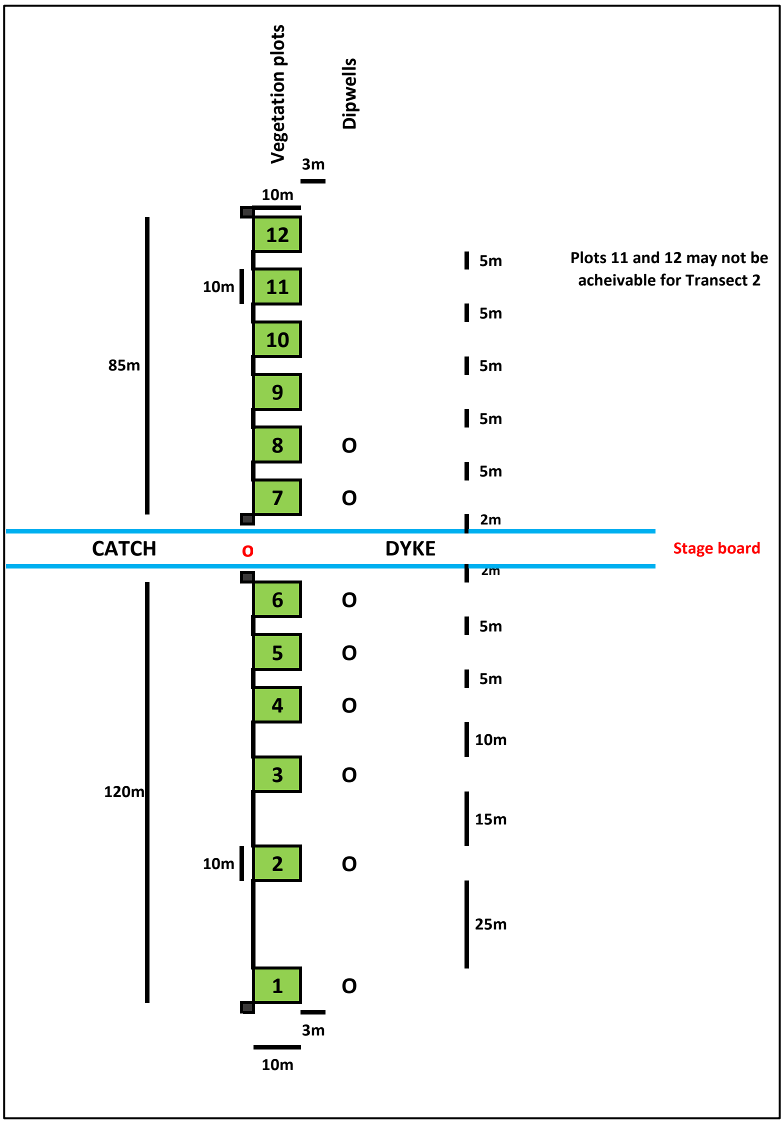
Such a function will involve core staff of the “host” organisation. In addition to reliable, long term resourcing, the function requires a level of stability within organisations that few seem to be able to maintain at the current time.

4.2 Long Term Change in Fen Vegetation

The degree to which fen vegetation changes over time is not well understood. Site managers sometimes express the view that particularly S24 communities – the core Broadland fen vegetation – seems rather stable with little obvious change year on year. However, no data has been produced to corroborate such anecdotal evidence.

A review of the literature suggests there are very few long term studies of fens available (e.g. Harding 1993, Fojt and Harding 1995) and few if any which encompass core Broadland fen communities. Often studies examine the effect of perturbations on fen vegetation, but sites where the environment is stable or where change may be subtle or long term are of less interest.

Figure 3: Vegetation and Hydrological Monitoring Transect Suggested for Decoy Marshes Acle, Assessing Success of Restoration of Catchdykes (OHES 2016a)



Lack of knowledge of the dynamics of fens means it is difficult to interpret the results of monitoring and to separate change attributable to wider environmental change, to autogenic change (i.e. change arising from fen community dynamics) or to interventions such as site management. It is difficult for site managers to decide if and when a management intervention is needed to alter the course of perceived community change.

Two categories of long term change are of interest:

1. Change associated with variation in broad sets of potentially interlinked environmental variables – climate change, changes to water levels or eco-hydrology, changes in nutrients or water quality. Data collection is open-ended rather than time-limited
2. Change related to a specific process or linked to a specific question for which an answer is being sought. Studies are conducted for as long as required to answer the question.

The first is considered **surveillance monitoring**, and is the territory of long term monitoring of permanent plots discussed in *Report 1: Recommended Vegetation and Hydrological Monitoring in Broadland*.

The second is **research monitoring**. Research Monitoring is distinguished from other forms of research discussed below by the broadness of themes examined and by the timespan of data collection. Investigations into some topics characterised by continuous or unstable processes could be for very long time periods. Inertia in plant communities means that subtle changes to management or the environment can take a long time to manifest as significant change to vegetation.

In practise, the timeframe for most research is led by funding and by the classic 3-4 year Studentship. Only the most significant and immediate ecological change will be detected. Because conservation is a long term process the results of such research could be misleading and result in the wrong change to management strategies. **Research monitoring** sits between surveillance monitoring and typical short-term research.

There is therefore a need to move the emphasis from short term research projects to long term research monitoring. Most of the issues described below would benefit from a long term approach. The resources and institutional infrastructure required to undertake long term work are not in place.

4.3 The Economic and Social Sustainability of Fens.

For recent generations, fens have largely been outside the rural economy. With the exception of stands of dense sedge and reed which can be harvested for thatching, fens have been of little interest to any other than conservation organisations and the few individuals with a passion for wetlands. Consequently, practically all of the work to conserve fens is financially negative and has to be supported by grant aid of some form – agri-environment, one-off grants or core funding by conservation organisations. This is unlikely to be sustainable, with many income streams under threat and the competition for remaining funding intensifying. The vulnerability of the conservation effort to these changes has long been recognised, and was highlighted in Harding (2013).

Alternative ways of valuing fens and therefore of funding their conservation may need to be developed (Figure 4). Ecosystem services are the focus here. The range of societal benefits provided by fens is very wide. It includes carbon storage (Webster et al 2016), eco- and landscape tourism, climate change mitigation, water resources management including flood attenuation, water quality management, fisheries, angling and recreation, archaeological conservation and economic assets such as fibre and energy production, livestock and agriculture. In addition, the social value of fens needs to be elucidated. As truly wild areas, their value in terms of access to nature should be explored fully. Health and wellbeing are increasingly viewed as important benefits of countryside and nature conservation, with conservation organisations working more and more with health service providers. Development of these themes for advocacy would be a priority.

Figure 4. People enjoying fens.

A further concern is the detachment of communities from fens. Because although part of the view in many areas of the Broads, they are rather hidden, generally inaccessible, quite specialist and of no economic value, apart from visitors to nature reserves, few people other than site managers and special interest visitors have any contact with wider private fen areas. Their public profile is low, unless they support charismatic bird species, and even for those interested in nature, fens compare poorly in terms of profile with woods, meadows, heaths and the coast. With such a low level of public engagement, it is difficult to build much support for fen conservation, to lever funding or to effect policy change.

No research on public attitudes to fens and their conservation, either locally or more widely, was seen during this project. A better understanding of public perceptions and how to promote fens appears essential for the long term future of the resource. Evaluation of past stakeholder engagement initiatives would help inform further initiatives. Deeper social science research to evaluate different methods of engaging stakeholders to deepen understanding of and investment in sustainable wetland management would be helpful.

4.4 Fen Hydrochemistry

Hydrochemistry is an important driver of fen ecology. The three variables of greatest current concern in the Broads are salinity, nutrient enrichment and change in pH largely towards acidification. The latter is dealt with in a separate theme below.

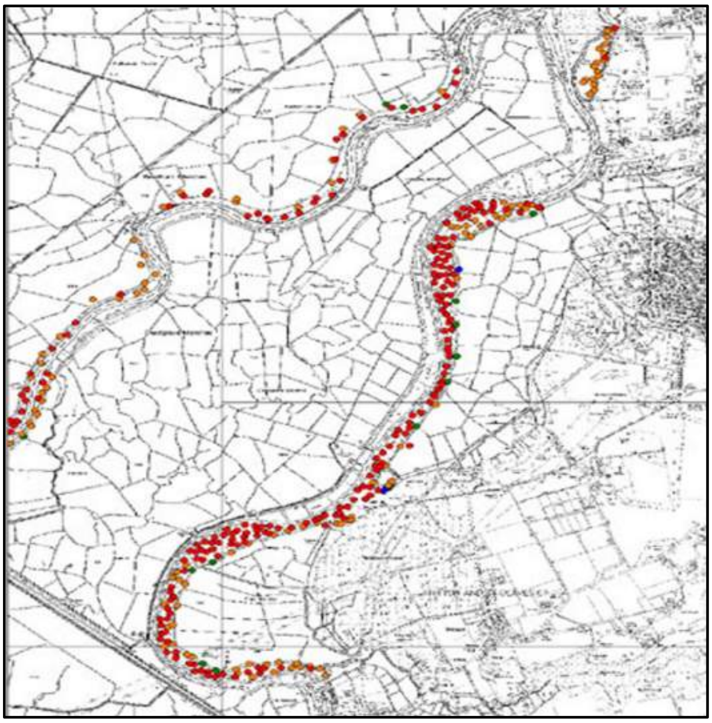
Nutrient enrichment may be derived from four sources in the Broads: rainfall, catchment water from the surrounding upland either by surface or groundwater, catchment water from irrigating water courses, or from within the site. Their relative importance has never been evaluated in the Broads, partly because nutrient budgets are so site specific and in fact can vary substantially within a site or even compartment. This makes evaluating the significance of this issue very difficult and devising suitable responses even more so.

Rainfall may be the least of the enrichment sources. The water quality of rivers has improved in the last 20 years and may be within acceptable limits for some fen types, but not perhaps those dependent on the lowest nutrient levels which are often the most valuable. Impacts of enriched surface water depends on site specific details such as topography, peat hydraulics, river regime and location of vulnerable plant communities, all of which determine the degree of irrigation by catchment water. Run-off and contamination from adjacent intensive land uses is a known problem (e.g. OHES 2014), but is poorly quantified and rarely objectively assessed for individual sites. Tools for doing so are not well developed, other than resource intensive catchment nutrient modelling. The nutrient dynamics within fen compartments may be an underestimated source of nutrients, especially where peat surfaces are drying, subject to grazing or other disturbances. There is relatively little data on these issues.

A significant issue is developing a meaningful measure of nutrients which can be related to fen community ecology and condition. Wheeler *et al* (1991) could find no direct measure of nutrients (such as phosphate or total P) because processes in the soil or water moderated levels of mineral determinands, or moderated the way that plants responded to given levels (e.g. high levels of acidity reduced a plants ability to uptake available nutrients). Hence Wheeler used direct measures of fertility (dry weight of seedlings grown on a sample of soil in the lab) to characterise fen communities, but this is difficult to replicate and to relate to field measurements of nutrients in waters or soils.

Salinity has become an increasing concern as tidal surges have increased and the penetration of salt into fens worsened (Figure 5). There has been relatively little research undertaken on

Figure 5: Effects of Salinity on Rond Fens in the Lower Waveney Valley, using Ellenburg Indicator Values. Red = High Salinity, Green = Moderate, Blue = Low. OHES 2011.



the topic (OHES 2011). The tolerance levels of different fen and faunal communities is poorly understood, and there has been relatively little study of individual plant and animal species within a Broads context. Similarly, the degree to which salinity penetrates fens, and into the core of fen compartments, is also not understood. It is likely to be highly site-dependent. The management response to increasing salinity has not be developed.

Finally, the hydro-chemical importance of fens to “downstream” habitats is poorly understood. How are catchment nutrients and solutes routed through fens and their soils to receptor bodies such as Broads and rivers (Figure 6)? Do fens have a role in moderating

Figure 6: To what extent do the fens surrounding buffer Little Broad at Upton Fen from nutrient enrichment?

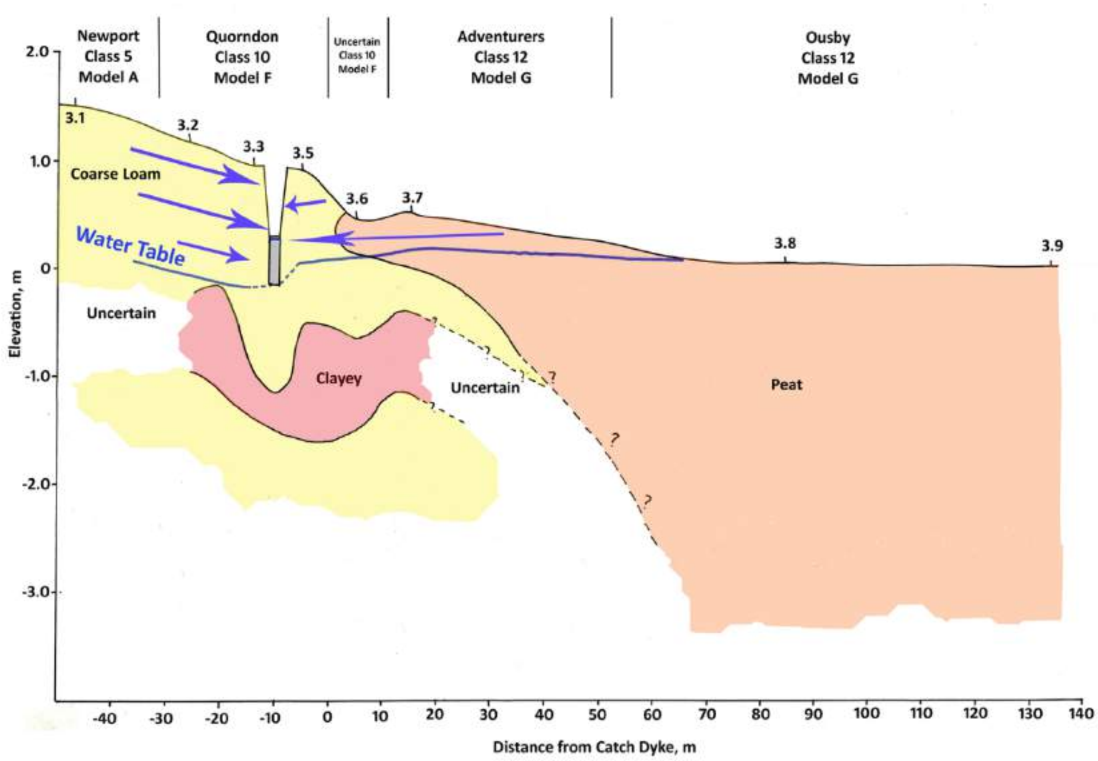
nutrient delivery to water bodies? In reviewing lake restoration options, Philips et al (2015) indicate that diffuse (land-based) nutrient supply to shallow lakes is now a major issue, particularly in offline Broads. Many Broads have substantive fen fringes which *may* interrupt the flow of nutrients from the valleys, but the level of benefit will depend on the internal nutrient dynamics of the fen. Peat-building fens could be expected to be nutrient sinks. Nutrient flows between upland, fens and Broads are not understood at the site scale, neither is our ability to manage fens to buffer lakes from nutrient flows. A complicating factor is that nutrient capture is likely to be damaging to the more ecologically valuable fen communities.

4.5 Hydrological Connectedness

The transition from open water through early swamp communities, floodplain fens and then to valley margins and dryland habitats is a key landscape character of intact Broadland. The existence of such a landscape depends on full hydrological connectedness from river margin to upland dryland.

The potential influence of catch dykes (the dyke which runs along parallel to the highland margin) on hydrological connectedness has been an increasing concern to site managers in the last 5-10 years. Their role in effecting conversion to arable of the dryland transition was first discussed in ELP (2010), as an explanation for the loss of a significant part of the lake-dry field sequence described by Pallis (1911). Drawing on a wide range of research in the UK and in Europe, OHES (2014) detailed the ways in which catch dykes can influence the value of a margin, the different eco-hydrological vulnerabilities to catch dykes and possible remedial solutions. Two sites underwent more detailed analysis (e.g. Figure 7), with site specific remedies detailed (OHES 2016a, b). Catch dykes and their impacts remains a key issue for Broadland fens, but site specific work is still at an early stage.

Figure 7 : Impacts of the catch dyke on the valley margin ecology and hydrology, Decoy Carr, Acle. From Harding (2016a).



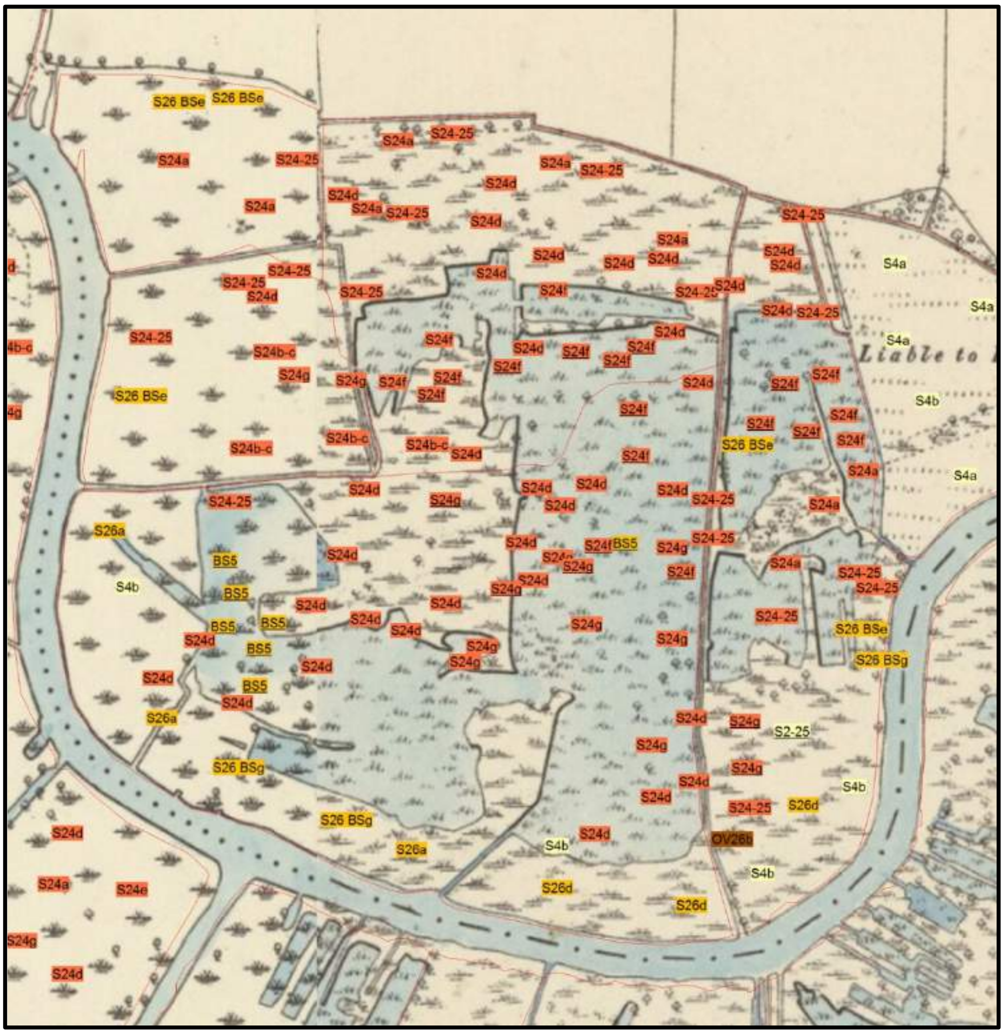
Other aspects of hydrological connectedness are important in fen conservation. The connection of open and embanked fens to the river via their dyke networks needs better understanding. Connections have sometimes been closed due to concerns about river water quality and its impact on fen and ditch systems. Nutrient levels in rivers may have declined recently, but salinity levels have not, and both may be above tolerance levels. High connectedness can in some circumstances be problematic, but the eco-hydrological function of the river-fen dyke-fen community relationships are poorly understood.

The loss of pioneer swamp and fen communities at the transition between water and land has been well documented and much lamented (George 1992, ELP 2010, Philips et al 2015). It was the pioneer communities which provided connectedness between fen and water, but are now often replaced by hard boundaries. The importance of the transitional margin is reasonably well understood for fen evolution and succession. Its importance for shallow lake hydro-dynamics and aquatic ecology is poorly explained.

4.6 *Managing the Hydroseral Succession*[1]

Turbaries are in essence an early successional stage of fens, usually located within expanses of mature fen. Conservation organisations have invested significantly in the excavation of turf ponds in the Broads. This is because old turbaries are known to support some of the most distinctive plant communities and the richest stands of fen vegetation (See Figure 8. ELP 2010, Giller and Wheeler 1986, Parmenter 1995, Wheeler 1978, Wheeler et al 2009). These include

Figure 8: Correlation of Plant Communities with Old Peat Diggings at Ebb and Flow Marshes. Higher quality S24 and the *Sphagnum-Dryopteris* acid community BS5 are concentrated in the old peat cuttings tinted blue. (Harding 2016b)



the wetter and richer sub-communities of S24 and Wheeler's *Peucedano-Phragmitetum-Caricitosum* community (Wheeler 1980a,b) which was never adequately accommodated in the

[1] Hydroseral succession refers to the sequence of habitats present from wholly aquatic Broads phase through to habitats of the dry valley slopes.

NVC but lies somewhere towards the boundary between S24 and M9. The influence of substrate on vegetation development is broadly understood for clay and peat (Giller and Wheeler 1986). The role of hover floating across turf ponds in facilitating the growth of acid vegetation types is less understood (Giller and Wheeler 1988, ELP 2010). The evolution of hover itself is not understood, but several mechanisms have been proposed, with more than one mechanism probably involved. Otherwise, the ecohydrology of terrestrialising turbaries and the mechanisms by which fen communities are assembled on fresh surfaces at a given site are poorly known.

Site managers have been surprised sometimes that some excavations develop little or no vegetation in the subsequent years. This has also been reported in the Netherlands, where succession of turf ponds to equivalents of M9 has been rare. In the Broads, many of the turf ponds were excavated in poor quality scrub and on dryer fen, while others were in better quality fen. However, the influence of starting conditions on the end result is unknown. Turbary succession in the Netherlands has been the subject of a concerted research project, reported in 2016. However, only an English summary is available[2]. It suggests that water and sediment chemistry are the key determinands of success (with low nutrient and high calcium promoting success), with turf pond shape, depth, sediment characteristics and edge profile also being important, as is control of grazing by wildfowl and rodents, and the promotion of mowing.

A second major form of early successional fens is the transition from aquatic conditions to terrestrial fen. Swamps such as S1 *Carex elata* swamp are now very rare and were poorly represented in the last Fen Resource Survey (ELP 2010). While establishing reedswamp has proven relatively easy, efforts to establishing new areas of more distinctive or complex early successional fens have not. Philips et al (2015) note very few sizeable areas of such habitat have been recreated. Interestingly, their report refers to such swamps as “littoral” communities, regarding them as edge of the lake habitats, whereas fen ecologists regard them as pioneer swamps, the edge of terrestrial habitats. Neither reflects their true ecological position and both are unsatisfactory ways of viewing the succession.

As a consequence of the loss of the semi-aquatic early successional swamps and the dryland transitional habitats described above, Broadland is now characterised by a much narrower range of fen types of the mid-part of the succession.

4.7 Re-creating Rare, Complex, Species-rich or Distinctive Fen Vegetation

This theme deals with attempts to establish high quality fen (Figure 9) on sites without a recent history of fen cover. The emphasis is on species-rich and complex fens, rather than reedbeds whose establishment is well understood. The theme includes re-creating complex fens on other land-uses such as marsh, arable or long-standing woodland. It also includes developing target fen types from species-poor and degraded fen habitats. Re-creating fen may be important for the intrinsic interest of the fen itself, and also for connecting up isolated and fragmented fen parcels.

[2] How to reference the report is unknown and the data itself not accessible.

There appears to be relatively little research related to restoration of typical Broadland fen communities. Coulet (2008) looked at establishing S24 fen on fen meadow at Woodbastwick,

Figure 9 : Species-rich and complex fens have proven difficult to re-establish.

but the results were not conclusive. There is little established practise. Fen is being re-established at South Fen and Tonnage Bridge Marshes, and there has been various other fen re-creation attempts through agri-environment schemes, but these are usually small in scale. Many of the existing schemes depend on restoration of a target water level together with relaxation of management (either cutting or grazing), but little direct intervention in species richness. More aggressive interventions have not been well documented.

Seeding or direct planting are obvious interventions but are rarely undertaken or formally monitored. Green hay has been used, and there is some practise in seeding moss (e.g. at Greifswald in Germany[3]). Acquisition of degraded or non-fen land in current Broadland projects offers the opportunity to research methods and benefits of seeding/direct planting.

Generally, there is no systematic monitoring of the success of re-creation or enrichment schemes, and limited collation of good or poor practise for community change. There is limited evidence-based guidance to help develop new schemes. There may be more information for non-Broadland habitats included in The Fen Management Handbook (McBride, 2011) such as valley fens and poor fens, but this information needs to be collated and sifted to include data that can be applied in the Broads context.

4.8 Acidification of Fens

Acid or poor-fen vegetation is uncommon in the essentially calcareous, rich-fen system of Broadland. Characterised by *Sphagnum* moss, and at its most developed form becoming the BS5 *Dryopteris cristatus-Sphagnum species* community described in the Fen Resource Survey (ELP 2010), Broadland poor-fen harbours uncommon species and is also an SAC feature habitat. It is usually very small in extent, often associated with young scrub and is considered to be hydrologically fragile. All these factors mean it is of significant conservation concern, with particular site management needs. And yet it is relatively poorly understood, despite

[3] See for instance http://www.paludiculture.uni-greifswald.de/en/projekte/sphagnumfarming/projekte.php

being recognised in the early accounts (Pallis 1911) and in more recent work (Giller and Wheeler 1988, George 1992, OHES 2010). The notion that these acid noda may be incipient raised mires, or at least one of the paths of successional development from rich-fen, has also long been recognised (Giller and Wheeler 1988, Wheeler et al 2009).

A marked expansion of acid or poor-fen vegetation at Catfield Fen, could not be satisfied beyond reasonable scientific doubt this would not adversely effect site integrity under the Habitats Directive. This expansion and its causes have been well evidenced, with withdrawal of calcareous groundwater by an adjacent groundwater abstraction being a significant contributory factor with a range of factors playing a part. However generally, the overall acid and base rich fen ecology, the Broadland sites, long term trends and management requirements of this key community are not well known. In terms of management, the role of maintaining scrub cover is uncertain, as is the benefits or risks of mowing over such fen. The degree to which literature on related poor fen and bogs may be helpful is unclear.

If the community is a successional stage from rich fen, then the potential conflict between its expansion and consequent loss of potentially valuable calcareous habitat will need to be resolved, at both a policy level and a site level.

4.9 Fen Grazing and Animal-Plant Interactions

When fen grazing (Figure 10) was first developed, it was seen as something of a panacea – maintaining fens, taking off the standing crop, keeping scrub encroachment at bay, the progressive and gentle restoration of unmanaged fens, the creation of a heterogeneous habitat architecture, and the benefits particularly to invertebrates of finding an alternative to high-impact mowing. Most seductive of all, it was seen as low-resource requirement compared to mow and clear.

Figure 10. Dexter Cattle Grazing Valley Margin Habitats, Little Ouse Valley.

As schemes, have progressed, a certain degree of realism has dawned with grazing not meeting all aspirations, while significant disbenefits are emerging. Unforeseen impacts – on surface nutrients, on peat structure and on more sensitive components of the habitat such as *Cladium*, bryophyte mats and rare species of conservation concern such as *Liparis loeselii, Dryopteris cristatus* and some animal species – have restrained the wholescale roll out of grazing as the management tool of choice. Animal welfare issues have also hampered efforts to graze truly wet and wild fens. Finally, the costs and practicalities of fen grazing have both proven more challenging than conservationists would have wished.

Consideration of grazing has focussed on domestic animals. There may be significant impacts from the herds of deer now said to be expanding in the Broads. Deer are preferentially but not exclusively browsers, and their impacts on fen vegetation has never been studied. Their impact on substrate may be severe, as their high levels of activity and faithfulness to routeways cause deep poaching and mineralisation of surface peat.

There has been little or no objective data gathering on any of the issues associated with fen grazing. This is because of *methodological issues* described below, and because of the practical difficulties and costs associated with setting up studies, especially the more useful long term experimental studies. Hence all current understanding of fen grazing in the Broads is experiential and anecdotal.

A second area of animal-plant interactions needing investigation is the role of animals in distributing propagules and therefore affecting plant community composition. The ability of stock to move seed or plant fragments within a site being grazed, or from site to site, could be significant and could be manipulated by wetland managers, e.g. moving stock from species-rich to species-poor areas. Wild grazers such as deer and small herbivores could be significant in distributing propagules, while birds such as geese and wildfowl may distribute seed around a very wide geographic area. Animals could have an adverse impact if the species transported were non-native and invasive aliens.

4.10 Fen Cutting

Mowing has advantages and disadvantages in terms of management for conservation (Figure 11). It is arguably the best prescription for maximising botanical diversity and reducing

Figure 11: Volunteers mowing mixed fens.

nutrients, but is most labour intensive and produces volumes of arisings. Depending on patch size, it can also be a poorer option compared to grazing for invertebrates. A partial answer has been mechanisation, latterly with the Fen Harvester, but there have been concerns about the impact of the machine on surface peat structure and on sensitive species such as bryophytes and *Cladium*. The Harvester has been a greater focus of attention in this respect than grazing (until perhaps lately), although the damage done by fen harvester tracks compared to stock walkways, particularly deer trackways, may be modest. There have been attempts to assess impacts (See Broads Authority File Note *Fen Harvester 2014/15 Monitoring Results*) but the study is just starting and is building in controls and replicates on comparable sites, although more could be done. A full-scale comparison of fen harvester versus other forms of mowing versus grazing is required on consistent stands of fen vegetation.

While there is some literature on fen mowing and its impacts on diversity (e.g. Rowell et al 1985), and some of the principles were established early on (Godwin 1929, 1941), these studies are rarely on directly comparable floodplain fen vegetation types, and are not Broadland-based. While such studies inform general ecological principles and management prescriptions (e.g. McBride 2011) and we have a broad understanding of the ecological relationships between fen communities and the role of management treatments (well summarised in Rodwell 1991, 1995), it can be misleading to apply results of a relatively small numbers of studies from elsewhere to a different ecological context such as Broadland. For instance, the communities of turbaries are especially distinctive, as are a number of the sub-communities of S24 such as those dominated by *Cladium* or *Myrica gale*. Difficulties of managing the BS5 *Dryopteris cristatus-Sphagnum* fen has been referred to above. It is not possible to determine the minimum mowing requirement to meet a particular conservation objective such as maintaining favourable condition, maximising species diversity or maximising invertebrate diversity. Such studies probably need to be long term, and to include proper control plots.

4.11 Gathering the Knowledge: What is Known and What is Not

The above review is based on information already in the archives of Broads Authority and held by the author and other Partners. The last significant literature reviews to focus on the Broads were ELP (2010), supporting the Fen Resource Survey, and Harding (2005). The former had a narrow focus, while the latter is rather out of date, and George (1992) even more so. Other studies such as the catch dykes work (OHES 2014, 2016a,b) include more up to date material but are very issue-specific. Other reviews include McBride et al (2011) and Wheeler et al (2009) but these are more general and with a wider regional or national scope.

It is likely that a comprehensive review of the scientific and grey literature of say the last 10-15 years would provide many answers to issues raised above, or would at least allow them to be refined. A review of current practise among conservationists may yield further answers or provide guidance as to where research should be focussed. Certainly this work will need to be done before major research is commissioned, or as a preliminary to that research.

Regarding best practise in practical fen management, there are few collations, old or new. They usually take the form of management handbooks. Examples include:

- The Reedbed Management Handbook coordinated by RSPB focuses on reedbeds (Hawke and Jose 1996).
- The Fen Management Handbook, compiled by SNH with partners (McBride et al 2011), probably provides the best and most up to date collation of practise available but as mentioned is quite general with a broad national scope.

There is scope to update practise contained in these guides, and specifically to look for previously undocumented examples of practise relevant to the issues described in this report.

4.12 Arisings from Fen Management

The management of fens – in particular mowing, scrub clearance and ground lowering or turf pond excavation – produces a large amount of material which needs to be taken off the fen (Figure 12). The final use of this material is not resolved. The material is very bulky, there are major issues of removal and bulk transport and the problem is potentially never ending as they are the arisings largely of maintenance management. The arisings currently have no commercial value and their disposal represents a significant and ongoing cost. The problem is made worse by poor local transport and the dispersed nature of the source sites of the arisings.

Figure 12: Persistent Piles - A Conservation Problem.

The problem has been intractable for at least 40 years – ever since conservation management started – and is a limitation on the selection of management prescriptions and the volume of work that can be achieved. Further turf ponding will be constrained. Material has been deposited within areas of the fen thought of low quality and available as sacrificial sites. Some of these deposits are regrettable, and the practise has no future.

Recently, initiatives have started to examine what may be done with fen arisings, for example pelletising for fuel or for animal feed. The possible use of green arisings for composting, which *could* include composting of peat from turf pond excavation, has also been under development. The principle development agencies have been the Broads Authority and RSPB, with Defra recently funding a pilot research project, which is ongoing.

Initial results suggest the products have potential for a viable end use, but that practicalities and economics remain major impediments. Work continues. The potential was scoped in ELP (2010) but this is becoming out of date. More recent progress is summarised in a raft of technical notes and initial short technical reports coordinated by Sally Mills at RSPB.

This is a priority area of research because if the problem is not solved, the arisings issue will be perhaps one of the most significant blocks to progress in conservation of the fens in the Broads.

4.13 Methodology for Science Work

Perhaps surprisingly, the extensive areas of Broadland fens present considerable difficulty for field studies. Primary among these is the heterogeneity of the fens, in terms of vegetation and abiotic factors such as substrate type, hydrology and hydrochemistry. Because of the variability of the fens, finding tracts of vegetation with uniform starting conditions for management experiments is difficult. Reliability in science investigations requires controls and replicates. The problem proved so difficult that attempts to start management trials by leading conservation organisations were abandoned in the 1990s. With the Fen Ecological Survey we may now be in a good position to identify promising areas of fen for new fen studies.

Methodological issues are bad enough for manageable fen operations such as mowing. It is more difficult when considering impacts of grazing and scrub removal, or impacts on faunal groups which may be dispersed, mobile or composed of semi-dependent meta-populations. Grazing experiments are further compounded by the difficulty of managing grazing pressure and controlling plots for wild herbivores.

Overcoming these issues would require large scale experiments with concomitant resources.

A second issue is that of plot and sample size. The minimum area required to represent a Broadland plant community (and which is therefore appropriate for vegetation survey, experimental replicates and for long term monitoring) has never been properly defined. That it varies according to community architecture is well understood, but there has been no minimum area work undertaken on fens and the NVC itself is unclear as to exactly when quadrat sizes should be scaled up from 2 x 2m to 4 x 4m or 10 x 10m. As the decision is left to individual fieldworkers on the day, considerable variation may be expected. Kent (2012) has raised questions about the statistical and ecological viability of the minimum area and species-area curve[4] concepts. ELP (2010) discussed the potential problem of the varying sample sizes used within the NVC for defining communities. This of course goes to the very core of the nature of fen communities and should be resolved with some urgency.

[4] The species-area curve is the graph that demonstrates how the number of species recorded in a plot increases as the area of the plot increases. The rate of recruitment of additional species often declines rapidly after a certain size quadrat is reached. The smallest sampling area required to include the majority of characteristic species is considered the “minimal area”.

5. Funding Research

There are two broad areas of funding, both with pros and cons:

Partner Funded: here the main conservation organisations in the Broads directly funds the required research, as a contract to research institutions, individuals or other bodies. Benefits include focussed research with more guaranteed outputs. The disadvantages are the likely small budgets available, in part because the organisations face difficult financial times, and in part because few are used to funding significant research. Opportunities to fundraise for research among traditional donors are few. Direct funding is viable for small scale projects, or projects such as research monitoring and long-term studies where project time horizons are more suited to such organisations and where "little and occasionally" may be feasible. Funding for research into audience engagement is possible, as is research into practical techniques and sustainability issues via Government Departments.

Major Research Funds. These include the funding bodies that sustain major research initiatives. They would include the Natural Environment Research Council (NERC) and possibly the equivalent for social sciences. They fund Universities and research institutes mostly, and have significant budgets which could match some of the more aspirational research suggested above. However, such bodies focus at a national scale and on national priorities, and engagement on research topics and calls can be via NERC consultation, with application being via academic institutes, such as the Universities. Often, direct control of the direction and outputs of research would not be possible, although there is increasing requirement to demonstrate the impact of research. Universities tend to work in consortia or groupings – UEA for instance is with Anglia Ruskin, Kent and Plymouth. Anglia Ruskin have conducted detailed ecological and hydrological research at Wicken Fen and Great Fen in Cambridgeshire.

NERC has several current programmes – Biodiversity and Ecosystem Services Sustainability, and Valuing Nature (see http://www.nerc.ac.uk/research/funded/programmes/). In addition Innovation Funding to increase the uptake and impact of NERC funded research outputs by supporting knowledge exchange and benefits to end users, particularly businesses (see http://www.nerc.ac.uk/funding/available/schemes/innovation-projects/). In addition knowledge exchange and funding for placements and secondments is possible. NERC are in the early stages of developing a possible peatland resilience programme.

An example of an active, collaborative NERC funded programme is Hydroscape, a four-year programme which started in 2015. It "….aims to determine how stressors and connectivity interact to influence biodiversity and ecosystem function in freshwaters across Britain." The Broads are one of three research areas, the others being the Lake District and the freshwater bodies in the Glasgow area. The consortium is led by Stirling University but includes CEH and interestingly, British Trust for Ornithology, with the Broads Authority being a supporting partner. For further details see https://hydroscapeblog.wordpress.com/about/. While the programme is focused on open water, some of the hydrology and connectivity themes described for fens seem pertinent to this programme. Fens and their aquatic margins could also have a significant interactive role in the restoration and resilience management of water bodies, an area of Hydroscape research.

EU funding is clearly uncertain, although partnerships with member states – particularly the Netherlands and Denmark – could be fruitful. For the time being, LIFE and Interreg Funds are open for UK projects and partners.

The Leverhulme Trust (https://www.**leverhulme**.ac.uk) offers grants of up to £0.5M for work lasting up to 5 years, but competition is intense and probably needs to be through Universities.

Universities directly administer doctoral studentships but these would need to be funded by the Partnership. In addition, studies such as PhDs tend to be short term with a maximum of three annual field seasons, and there is limited guarantee that students will complete or write up, and no guarantee the course of research will maintain the original direction.

Universities offer other options such as internships (e.g. the PIPs scheme at UEA) or the possibility of MSc and PhD student projects. Talented and dedicated students can yield useful results, but such research is very short term and rather patchy in its reliability and usefulness.

6. Conclusion and Priority Research Questions

Progress in fen ecology and management has been relatively slow in the last 15 years. There seems little current academic interest in Broads fens. This report has outlined areas of particular concern. It is hoped this report will act as a catalyst for high-impact research by setting out themes and research projects. The following summarises specific research questions under the themes defined above:

Research Monitoring:

- What institutional arrangements and resourcing need to be put in place to enable long term research monitoring?
- If a partnership arrangement is required, who would be involved and who would coordinate? What would be the content of a Partnership Agreement?

Economic and Social Sustainability of Fens

- How can we apply an economic value to fens, other than through fen products.
- Can we clearly define the ecosystem services provided by fens, and can we assign an economic value to these services?
- What methods and tools can be developed to support advocacy of fens, their value to society and their requirement for conservation?
- Research on how the public perceive fens and their conservation would be a useful basis for further public engagement work. Perceptions should be assessed for particular audiences both local to the fens and those more distant.

Fen Hydrochemistry

- How should we measure fertility in fen soils in a way which is practical, ecologically meaningful and repeatable?
- How are nutrients and salinity routed through fen compartments? What factors aid movement of hydro-chemicals, what inhibits them?
- What are the nutrient budgets of individual fens? Can individual plant communities be assigned nutrient budgets within larger fen complexes?
- How do different fen communities respond to different levels of nutrients and salinity? Which species are particularly vulnerable?
- What management strategies can be deployed to mitigate harmful levels of nutrients or salinity?
- What is the function of fens in moderating or buffering diffuse catchment nutrient flows to shallow lakes? What are the characteristics of fens which store catchment nutrients, and what are the characteristics of fens which contribute nutrients? What are the trade-offs between fen and lake conservation when considering using fens as shallow-lake buffer habitat?

Hydrological Connectedness:

- How are catch dykes affecting individual sites with differing eco-hydrological regimes and with varying catchment characteristics?

- Where remedial treatments require cooperation with neighbouring landowners, how is this best effected? Who is best placed to deliver catch dyke projects?
- How do fen communities respond to remedial treatments?
- What is the function of fen dykes in maintaining in-field fen conditions, in terms of both water quality and water levels? What is the role of the peat body in hydrological connectedness?
- How is connectedness best managed to optimise fen ecological condition in particular confirmations of dyke network, river flows and fen topography?
- If a fully functioning, fully connected floodplain is restored, how can negative impacts of poor water quality best be mitigated within a site?
- What is the eco-hydrological functioning of pioneer swamp communities, and how do they affect shallow lake hydrological processes, including hydrochemistry?

Hydroseral Succession

- Can an experimental approach identify which initial site conditions produce the highest quality fen communities following turf pond excavation?
- What turf pond design features (size, depth, shape etc.), and what post-excavation management, is required to establish high quality fen communities?
- Should we be re-excavating old turbaries, or excavate on adjacent undug peat?
- What is the likely conflict with (paleo) archaeological interests when digging into cut and uncut surfaces?
- What factors are limiting the natural re-establishment of the aquatic-to-early terrestrial transitional fen types? What is the relative importance of such factors?
- How can the initiation of this early phase aquatic-terrestrial succession be engineered?
- What processes govern the re-assembly of more diverse and distinctive fen types from the very early successional swamps? How can the process be managed?
- What are the mechanisms for hover to establish? Do different species respond in different ways? Can the processes be successfully managed?

Recreating Complex Fen Types.

- Which substrates promote restoration of high quality fen, and what are the key characteristics?
- Can these key site characteristics be re-engineered once lost or degraded?
- How can the re-assembly of species-rich or distinctive fen types be encouraged once environmental conditions have been stabilised?
- Which management techniques are required to restore degraded fen types to species rich complex fen types?

Acidification of Fens

- What are the key habitat characteristics which support poor-fen and transition mire in the Broads?
- Which WetMecs (*sensu* Wheeler et al 2009) accommodate acid noda?

- Is the frequency of acid noda increasing, and is the extent of existing locations increasing?
- What are the floristic relationships between acid noda and their surrounding vegetation types? Are the floristics of particular acid communities correlated with the floristics of the surrounding fen community, or largely independent of it? What is the nature of the gradation between the two – sharp or diffuse?
- What is the role of management in maintaining acid communities?
- How should the potential conflict between expanding transition mire and declining rich-fen be resolved?

Fen Grazing and Animal-Plant Interactions

- What is the nature of the relationship between grazing strategy and consequential fen habitat structure? Are there similar relationships for invertebrate communities, and are the resultant habitat structures and invertebrate communities correlated or independent?
- What are the effects on peat structure and shallow peat hydrology of different grazing strategies? Are the impacts on peat structure and hydrology different in wet fens compared to dryer sites?
- What is the effect of stock manuring on available nutrients (fertility) at the fen surface, and what is the role of hydrological processes such as rainwash and surface flooding in distributing such available nutrient?
- How do current deer herds affect the ecology of fens? Is there an interaction with domestic stock? Consequently, should the deer herds be managed, and if so how?
- How do we calculate or specify densities of domestic and semi-feral herbivores when trying to manage a large-scale mosaic of habitats and communities?
- What are the dietary preferences of livestock when grazing fens? How does this vary between cattle/sheep/ponies and deer (and perhaps between breeds of the same stock). How would this knowledge inform selection of a particular grazing regime to achieve a particular management objective?
- In what ways do grazing patterns for a particular stock type vary between fen types – reedbeds, sedgebeds, mixed fen, acid fen, fen meadows etc? How does such knowledge influence specific grazing prescriptions?
- Are observational studies undertaken on Broadland fen sites, evaluating diet, habitat partitioning and the impact of different stock types and grazing densities, a useful approach to elucidating the above questions?
- What is the impact of switching from traditional mowing to grazing management on specific communities? Those containing a high proportion of *Cladium*, bryophyte mats, rare species and hover could be priorities.
- Which grazing regimes optimise fen invertebrate communities in different fen types?
- How do grazing animals distribute plant propagules? Do wild grazers have a significant impact? Are wildfowl significant vectors of plant propagules? Are grazers especially significant for invasive species?

Fen Cutting

- Is traditional, manual management as low-impact as has been assumed? How does this compare with grazing stock or use of low ground pressure equipment such as the fen harvester?
- What are the impacts of different mowing regimes on different Broadland fen types? The sub-communities of S24, hover vegetation, M9/M13 analogues, BS5 *Dryopteris cristatus-Sphagnum* fen and distinctive communities such as transition mire and early successional swamp would be priorities.
- What is the minimum level of mowing effort required to meet a conservation objective for a given community?
- How can fen mowing regimes be further optimised for invertebrate interest, across different fen habitat types?
- How can small scale mowing management be scaled up to the landscape scale? What is the best pattern of mowing and non-intervention to optimise for all species in, say, a whole river valley?

Gathering the Knowledge.

- A literature review is required to summarise what is known of the above issues in the scientific literature. This should include as much data as possible from foreign studies, especially Dutch, Danish and Scandinavian studies.
- A review of best practise in fen management is required. It should focus on East Anglian fens or at least fens analogous to Broadland fen types. The review should concentrate on sites where monitoring data or detailed historic survey data exists, so that objective assessment can be made of management interventions.

Arisings From Fen Management

- How can a viable end-use or commercial market for fen management arisings be secured?
- Can a use be identified which maximises financial returns and could offset the costs of fen management?

Methodology for Science Work

- Where in Broadland are there areas of relatively homogeneous vegetation which could be used for experimental study areas?
- What is the minimum areas for characteristic Broadland fen vegetation types? This will need to be resolved by new fieldwork.

Currently, strategic direction and the management of particular sites are both hampered by lack of good science in critical areas. Undertaking even a proportion of the research described above would result in a step change in conservation practise in the Broads. It would allow the conservation sector to emerge from a period of practise informed by experience and anecdotal evidence, to a period of much greater certainty underpinned by sound science.

Considerable challenges exist in order to initiate a renewed science effort; limited partner resources in the Broads, generating interest within the research community; funding meaningful research; and overcoming methodological limitations related to field sites and the long-term nature of good fen research. However, if these challenges can be overcome, Broadland conservation will move to a new level.

7. References

Coulet W., (2008) *The potential for fens on modified peat soils. The restoration of fen meadow into fen habitat in the Broads*. Broads Authority Norwich.

ELP (2010, 2014) *Fen Plant Communities Of Broadland Results Of A Comprehensive Survey 2005-2009*. Report to Broads Authority, Norwich. Minor amendments in 2014.

ELP and Ash, N. (2010) *New Opportunities For The Sustainable Management Of Fens: Reed Pelleting, Composting And The Productive Use Of Fen Harvests*. Report to the Broads Authority Norwich.

George, M (1992) *The Land-use, Ecology and Conservation of Broadland.* Packard Publishing, Chichester.

Fojt, W and Harding, MJ (1995) Thirty years of change in the vegetation communities of three valley mires in Suffolk, England. *J. Appl. Ecol*, v 32 561-577.

Giller, KE and Wheeler, BD (1986) Past peat cutting and present vegetation patterns in an undrained fen in the Norfolk Broadland. *Journal of Ecology, v74,* 219-247. 114

Giller, KE and Wheeler, BD (1988) Acidification and succession in a floodplain mire in the Norfolk Broadland, UK. *Journal of Ecology, v76,* 849

Godwin, H (1929) The sedge and litter of Wicken Fen. *Journal of Ecology,* v.17, 148-170.

Godwin, H (1941) Studies in the ecology of Wicken Fen. IV Crop taking experiments. *Journal of Ecology,* v.29, 83-106

Harding, MJ (1993) Redgrave and Lopham Fens, East Anglia, England. A case study of change in the flora and fauna due to groundwater abstraction. *Biological Conservation*, v 66 35-45.

Harding, MJ (2005) *Review Of Monitoring, Survey And Research Relating To Management Of Fens In Broadland.* Unpublished report to the Broads Authority Norwich.

Harding, MJ (2013) *Landscape Scale Projects Across the Wild Anglia Area*. Unpublished Report to WildAnglia, Norfolk County Council.

Hawke, CJ and Jose, PV (1996) *Reedbed Management for Commercial and Wildlife Interests*. RSPB.

Kent, M (2012) *Vegetation Description and Data Analysis. 2nd Edition.* Wiley Blackwell.

Lambert, J M (1951) Alluvial stratigraphy and vegetational succession in the region of the Bure valley broads. III Classification, status and distribution of communities. *J. Ecology,* v 39, 149-70.

A. McBride, I. Diack, N Droy, B. Hamill, P. Jones, J. Schutten, A. Skinner, and M. Street. (Eds) (2011) *The Fen Management Handbook*. Scottish Natural Heritage, Perth.

OHES (2011) *Analysis of salinity data from 2003-2008*. Report to Broads Authority, Norwich.

OHES (2014) *An Investigation into the Management of Catch Dykes in The Broads*. Report to Natural England, Norwich.

OHES (2016a) *Remedial Works for the Catch Dykes at Decoy Carr, Acle*. Report to Natural England, Norwich.

OHES (2016b) *Remedial Works for the Catch Dykes at Ebb and Flow Marshes*. Report to Natural England, Norwich.

Pallis, M (1911) The river valleys of east Norfolk: their aquatic and fen formations. In: Tansley AG (ed) *Types of British Vegetation*. pp214-245. Cambridge University Press.

Parmenter, J (1995) *The Broadland Fen Resource Survey. Vol. 1-5.* BARS Report 13a-f. Broads Authority, Norwich.

Phillips, G., Bennion, H., Perrow, M.R., Sayer, C.D., Spears, B.M., Willby, N. (2015) *A review of lake restoration practices and their performance in the Broads National Park, 1980-2013.* Report for Broads Authority, Norwich and Natural England.

Rodwell, J (Ed) (1991) *British Plant Communities. Volume 2. Mires and Heaths.* CUP.

Rodwell, J (Ed) (1995) *British Plant Communities. Volume 4. Aquatic Communities, Swamps and Tall Herb Fens.* CUP.

Rowell, TA, Guarino, L., and Harvey, HJ (1985) The experimental management of vegetation at Wicken Fen, Cambridgeshire. *Journal of Applied Ecology,* v. 22, 217-227

Webster, EJ, Belyea LR and Heppell, CM (2016) *Carbon Storage in floodplain fens along a gradient of saline influence*. Poster for conference available through Broads Authority. Research is at Queen Mary, Univ. of London, contact e.webster@qmul.ac.uk

Wheeler, BD (1978) The wetland plant communities of the River Ant valley in Norfolk. *Transactions of the Norfolk and Norwich Naturalists Society. V. 24, 153-87.*

Wheeler, BD (1980a) Plant communities of rich fen systems in England and Wales. I Introduction. Tall sedge and reed communities. *Journal of Ecology*. v. 68, 365-395

Wheeler, BD (1980b) Plant communities of rich fen systems in England and Wales. II Communities of calcareous mires. *Journal of Ecology*. v. 68, 405-20

Wheeler, BD, Shaw, SC and Tanner, K (2009) *A Wetland Framework For Impact Assessment at Statutory Sites In England and Wales.* Environment Agency Research Report, Bristol.

Wheeler, BD, Shaw, SC and Cook, RED (1991) Phytometric assessment of the fertility of undrained rich-fen soils. *Journal of Applied Ecology,* v. 29, 466-475