# M9 (*Carex rostrata – Calliergon cuspidatum/giganteum*) mire

## 5.1 Limitations of M9 and proposals to address these

Practical experience, and multivariate analyses suggests that the M9 unit of Rodwell (1991) has a number of limitations. From the perspective of the production of guidelines project, one difficulty is that it encompasses samples from a range of situations, making it particularly difficult to make generalisations about the community as a whole, or to specify threshold values.

Full examination and resolution of difficulties encountered with M9 was not undertaken, however some changes are proposed that it is believed alleviates some of the limitations of the unit. The justification for the changes are presented by Wheeler, Shaw and Tanner (2009) but the proposals made are represented below:

- M9a is (re-)defined on floristic grounds as an apparently smaller and more cohesive unit than that described by Rodwell. This means that it is largely restricted to containing samples from soakways and allied situations. As explained by Wheeler, Shaw and Tanner (2009), this reduction in compass is perhaps more apparent than real. It is possible that this unit could be considered to be a sub-community of a conflated M14, but this is considered premature and the soakway-based 'M9a' is regarded here as a separate community: M9-1, *Carex lasiocarpa – Scorpidium* mire.
- M9b contains the samples of M9 that occur in basins. It includes all of M9b and some stands previously allocated to M9a by Rodwell (1995), but which have closest floristic affinities with M9b. It corresponds fairly closely with Wheeler's original concept of *Acrocladio-Caricetum diandrae*. It is here regarded as a separate community: M9-2, *Carex diandra – Calliergon* mire).
- The PPc is floristically transitional between M9 and S24 but, as Rodwell (1995) suggested, it is probably better considered as a relative of M9 than S24 (this is certainly the case on ecohydrological grounds). It could be considered as a sub community of M9-2, but for simplicity is regarded here as a separate community: M9-3, *Carex diandra – Peucedanum palustre* mire.

There is a need to resolve better the relationship between M9-2 and S27, but this was not feasible within the constraints of the Wetland Framework study.

To avoid confusion, the units as recognised here have been given separate identities (M9-1, M9-2, M9-3) rather than regarded as M9a and M9b.

# M9-1 (*Carex lasiocarpa – Scorpidium*) mire

## 6.1 Context

Examples of the M9-1 community have been included in the ‘alkaline fens’, SAC feature, as well as ‘transition mire and quaking bog’, and ‘calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*’.

### 6.1.1 Floristic composition

A distinct type of vegetation of sluggish soakways, water tracks and some gentle soligenous slopes. It corresponds broadly, but not exactly, to the sub-community M9a of Rodwell (1991).

The most constant species are: *Carex rostrata, Carex panicea, Eriophorum angustifolium, Molinia caerulea, Potamogeton polygonifolius* and the bryophytes *Aneura pinguis, Campylium stellatum, Drepanocladus revolvens* and *Scorpidium scorpioides*.

The vegetation is moderately species-rich (10 to 46 species per sample), usually dominated by sedges of medium height, often presiding over an open stand of vegetation, with bare mud and open water, often with extensive carpets of bryophytes. *Carex rostrata* is the most typical and constant species of sedge (*Carex lasiocarpa* occurs quite frequently but only in about 30 per cent of the samples and *Carex diandra* is not very characteristic (10 per cent of samples)). However, some stands lack a medium sedge layer and lower-growing species predominate. The most widespread of these is *Carex panicea*, but a variety of other cyperaceous species can also occur, including *Eleocharis multicaulis, E. quinqueflora* and, sometimes, *Schoenus nigricans*. A total of 25 rare mire species were recorded within this vegetation type including *Andromeda polifolia, Calliergon giganteum, Calliergon sarmentosum, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Cladium mariscus, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Drosera intermedia, Epipactis palustris, Eriophorum gracile, Eriophorum latifolium, Hammarbya paludosa, Oenanthe lachenalii, Osmunda regalis, Rhizomnium pseudopunctatum, Selaginella selaginoides, Sphagnum contortum, Sphagnum subsecundum, Sphagnum warnstorfii, Thuidium deliculatum, Utricularia intermedia, Utricularia minor*.

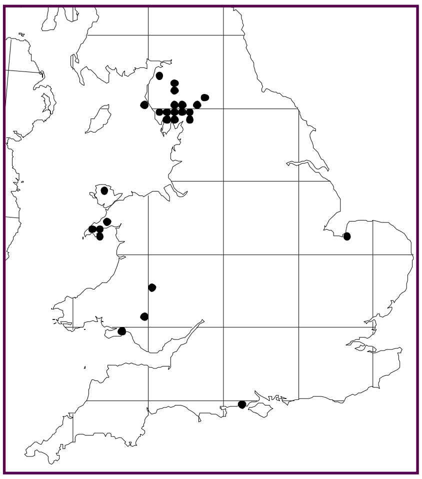
The bryophyte layer is often well developed. *Campylium stellatum*, *Drepanocladus revolvens* and *Scorpidium scorpioides* are the most constant and, very often, most abundant species, but Sphagna are also often well represented, especially those species that are particularly tolerant of base-rich conditions. Both the widespread *S. subnitens* and the rarer *S. contortum* were each recorded in about half of the samples, often with quite high cover. Other *Sphagnum* species occur with lower constancy, such as *Sphagnum auriculatum, S. palustre, S. recurvum*.

### 6.1.2 Distribution

M9-1 is widely distributed, but uncommon in England and Wales (recorded from 52 wetland sites (Figure 6.1)). The greatest concentration of sites is in the North and West, particularly from parts of South Cumbria, such as Subberthwaite Common, where it may be a variant of M14. The samples from East Anglia and the New Forest are transitional to M14 and some other samples from these sites have been allocated to M14. The M9-1 samples differ from their M14 counterparts by the absence of *Schoenus* and *Narthecium*, but the distinction is small and a case could be made for allocating these samples to M14. The community typically occupies flow lines and soligenous slopes irrigated with fairly base-rich water, though in many instances the water is not as base-rich as in locations supporting M9-2.

Some (rather anomalous) examples of this community have been recorded from Crymlyn Bog (Glamorgan) (such as alongside the head of the Glan-y-Wern canal), and these contribute important populations of some less common species (such as *Carex limosa*, *Eriophorum gracile*).

**Figure 6.1 Distribution of M9-1 in England and Wales (from FenBASE database)**



### 6.1.3 Landscape situation and topography

Most characteristic of valleyhead sites, where it occurs in small runnels, soakways or, occasionally, on soligenous slopes. Some examples are associated with valleyhead basins, on the slopes and small valleys feeding into the basins, but a few examples are known in the basin proper. In this situation, M9-1 mainly occurs near the margins and associated with localised water inflows, but in a few cases it occupies a soakway across part of the basin (*cf.* M29).

### 6.1.4 Substratum

In most sites the vegetation forms a fairly soft mat. In some it is quaking and semi-floating, though the degree of solidity and the depth of fluid peat/water beneath it varies (values of 30 to 50 cm are typical). Beneath the upper horizons, peat depth varies from more than three metres depth in some valleyhead troughs to a skeletal deposit. Some examples of the community, especially on or adjoining soligenous slopes, have developed over a soft, often muddy, deposit rather than a quaking one. Examples from Crymlyn Bog occupy a quaking surface over some six metres of peat, but these are exceptional.

Most examples of the community are not specifically associated with calcareous rocks (an example from Tarn Moor (Sunbiggin) is an exception). The Cumbrian examples are mostly associated with various Silurian deposits, and this applies also to some examples from Wales. However, the community is associated with a range of deposits, and in some cases (such as Rhyd-y-Clafdy, Cors Geirch (Caernarfon)) it is apparently fed by groundwater from a sand and gravel minor aquifer.

### 6.1.5 Zonation and succession

Many examples typically occur as soakways and water tracks within valleyhead mires, with zonation depending on hydro-topographical context. Examples sometimes occur as more or less isolated mire units, bordered by drier habitats, but the majority are embedded within a wider mire habitat. Adjoining communities depend upon the topographical context and base status, and can include M10, M13 or M22. However, the less base-rich examples are typically flanked by M21 vegetation, where they may form part of an axial zonation from a watercourse through M9-1 to soligenous slopes. In certain circumstances M9-1 forms discrete trails within topogenous hollows, probably marking zones of greater water flow, and in these circumstances it may be flanked by various topogenous communities, including M9-2 and various poor-fen surfaces.

Little information is available on successional trends in this community. Most examples are so small that they have not received consideration separate from the larger, flanking mires, and the development of this community is probably inextricably bound with these. It is possible that many examples of M9-1 may be too wet for scrub encroachment, but their frequently narrow width means that they could easily become overtopped by a canopy of woody plants developed on drier terrain alongside, a process which would probably result in loss of the community as a distinctive entity, as most of its species are sun-loving.

In the small number of locations where M9-1 occurs in topogenous locations, it appears to form part of the hydroseral process, albeit one that may be disruptive of the generic hydroseral pattern. The vegetation of the north-western arm of Cors Gyfelog (Caernarfon) contains stands that have closest affinities to M9-1 (though they are also closely related to M9-2 and M29). This site seems likely to be a reflooded peat cutting and the M9-1 stand trails may perhaps be seen as units that are emerging in the hydroseral succession, and in this context they may be vulnerable to surface acidification or scrub encroachment (or both). However, they are not good examples of M9-1 (or, indeed, of any other described community) and may be considered anomalous. Nonetheless, it is clear that some examples of good M9-1 are late-successional derivatives of terrestrialisation in lake basins. As is the case with M21, examples of M9-1 in the valleyhead troughs of Southern Cumbria in some cases occupy troughs which have developed over, and expanded beyond, former lake basins. The peat infill has sometimes obliterated any surface evidence for the former lake basin and the water flow which supports the stands of M9-1 occurs across the surface of what is now a gently sloping trough of peat, superimposed upon the former lake basin.

## 6.2 Supply mechanism and conceptual model

Forty-five per cent of samples were identified as occurring within WETMEC 19 (Flow Tracks, such as many of the Subberthwaite Common mires (Cumbria)), with 20 % within WETMEC 15 (seepage Flow Tracks, such as Tarn Moor, Sunbiggin (Cumbria)). Ten per cent occurred within each of WETMECs 10, 13 and 18.

The examples of M9-1 examined are mainly associated with axial soakways embedded within valleyhead systems, and these are often flanked by percolation troughs or soligenous slopes. In a few cases M9-1 occupies flow lines within soligenous slopes, and very occasionally it forms the greater part of a gently sloping soligenous surface.

Some M9-1 stands are unquestionably primarily groundwater-fed, including those at Cors Geirch, Tarn Moor (Sunbiggin) and the examples transitional to M14 on the Lower Greensand in Norfolk and Eocene deposits in the New Forest. In many other cases the role of groundwater is much less certain, and this is reflected in the allocation of the majority of samples to the flow tracks of WETMEC 19. These are all in locations where hydrogeological, hydro-topographical and climatic circumstances suggest that if groundwater supply occurs at all, it is likely to be supplemented significantly by surface water inflow into the mires. This is particularly the case for the important examples in South Cumbria. These are largely located upon Silurian deposits, the importance of which for groundwater supply is little understood. In many instances, fracturing of the upper horizons of these deposits may form a minor aquifer that contributes to the water budget of the mires. It is tempting to suggest that groundwater outflow from such rocks may provide the main source of base-enrichment associated with M9-1, if not necessarily the main source of water.

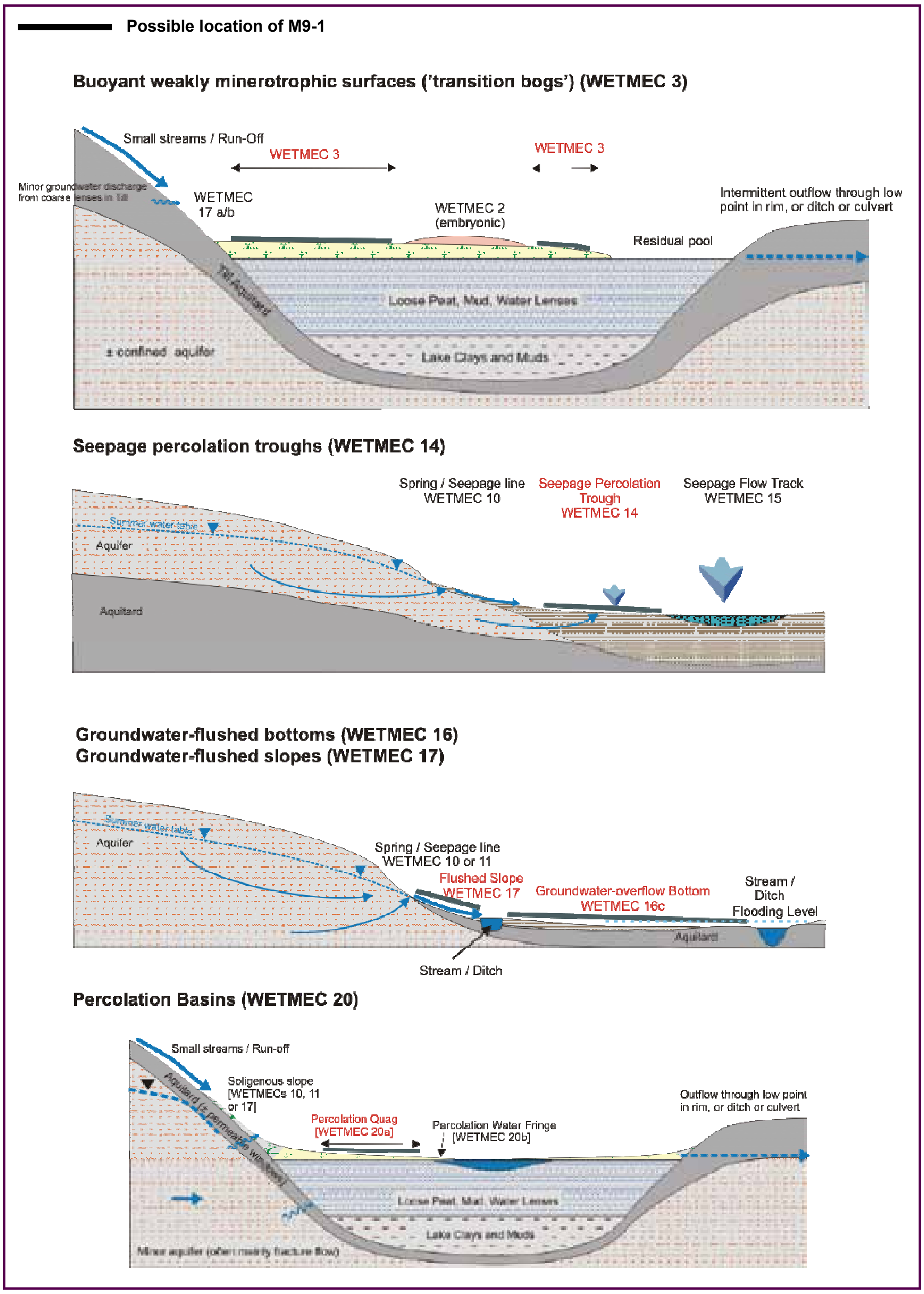
Examples of M9-1 are mostly associated with summer-wet conditions. Four mechanisms appear to contribute to this, though not all necessarily occur in each example: (i) a fairly consistent water supply, provided by high rates of groundwater outflow, or high rainfall (or both); (ii) association with surface water flow lines, either through the community or as small water tracks or watercourses alongside it; (iii) a quaking surface which probably has some hydro-regulatory function; (iv) semi-fluid substratum below the surface, which may provide a preferential flow path.

The main water supply mechanisms are illustrated schematically in Figure 6.2.

**Table 6.1 Rainfall, potential evaporation and water table data for M9-1**

| | Mean | Min | Max |
|---|---|---|---|
| Rainfall (mm $a^{-1}$) | 1,447 | 1,030 | 1,891 |
| Potential Evaporation (mm $a^{-1}$) | 547 | 454 | 646 |
| Mean Summer Water Table (cm agl or bgl) | -3 | -25 | 36 |

### Figure 6.2 Schematic representation of the major water supply mechanisms to M9-1 (after Wheeler, Shaw and Tanner, 2009)



## 6.3 Regimes

### 6.3.1 Water

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 6.1 together with mean recorded values for summer water table associated with stands.

The water table is normally consistently high beneath M9-1 stands, usually just above or below the surface, sometimes forming shallow swamp (especially in winter or after heavy rain). Although a few examples with low summer water tables were recorded, they are exceptional (only 4% of samples had a summer water table less than one cm bgl) and the cause of this is unknown, though they were all associated with more solid peat infills than is usually the case. The highest water tables were associated with unconsolidated surfaces and were probably, in part, an artefact associated with depression of the vegetation raft during sampling.

Specific time-series data for stands of M9 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

#### Optimal water levels

- Typically, consistently at or just above surface level year round, particularly where forming a floating raft.
- Association with a buoyant surface provides some vertical mobility and hydrological stability.
- In some of the broader, flatter examples, flooding of the surface with base-rich water may be important in constraining the extensive development of rain-fed nuclei and succession to community types associated with more acidic conditions.
- Some examples of this community have been recorded in low water conditions, but these are exceptional, and probably not in equilibrium with the water regime.
- Examples of this community appear to be associated with water movement, occurring either in soakways, alongside water tracks, or (occasionally) near the margins of some basins where water inflow is apparent or suspected. Water flow data are not available, but are generally likely to be greater than in M9-2 and M9-3.

#### Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can therefore be speculated that these would lead to a loss of wetland species and increased representation by dryland species. In instances where the community occupies axial soakways it can be, and in some locations almost certainly has been, destroyed by ditching.
- Prolonged, deep inundation leading to stagnation, particularly in the spring or summer, is likely to kill some species and lead to development of less diverse vegetation types.

**Table 6.2** pH, conductivity and substratum fertility measured in stands of M9-1

| Variable | Mean | ±SE | Min | Max |
|---|---|---|---|---|
| Water pH | 6.0 | 0.03 | 5.0 | 6.9 |
| Soil pH | 5.8 | 0.04 | 4.8 | 7.4 |
| Water conductivity (Kcorr μS $cm^{-1}$) | 249 | 1.8 | 33 | 1,051 |
| Substratum fertility[10] (mg phytometer) | 6.7 | 0.15 | 4 | 14 |

[10] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility ‹ 8 mg, high fertility › 18 mg.

#### 6.3.2 Nutrients/hydrochemistry

Typically found in situations of intermediate to fairly high base status with respect to the main rich and poor-fen communities, although it covers a wide range. It is very likely that it would be possible to divide the community into two floristic sub-communities that would correspond respectively to samples from intermediate and fairly high base-status locations, but this is outwith the scope of the present project. Conditions are generally of low or moderate fertility, and on average samples are slightly, but significantly, less fertile than those of the related M9-2.

Figures for pH, conductivity and substratum fertility measured in stands of M9 are presented in Table 6.2.

#### 6.3.3 Management

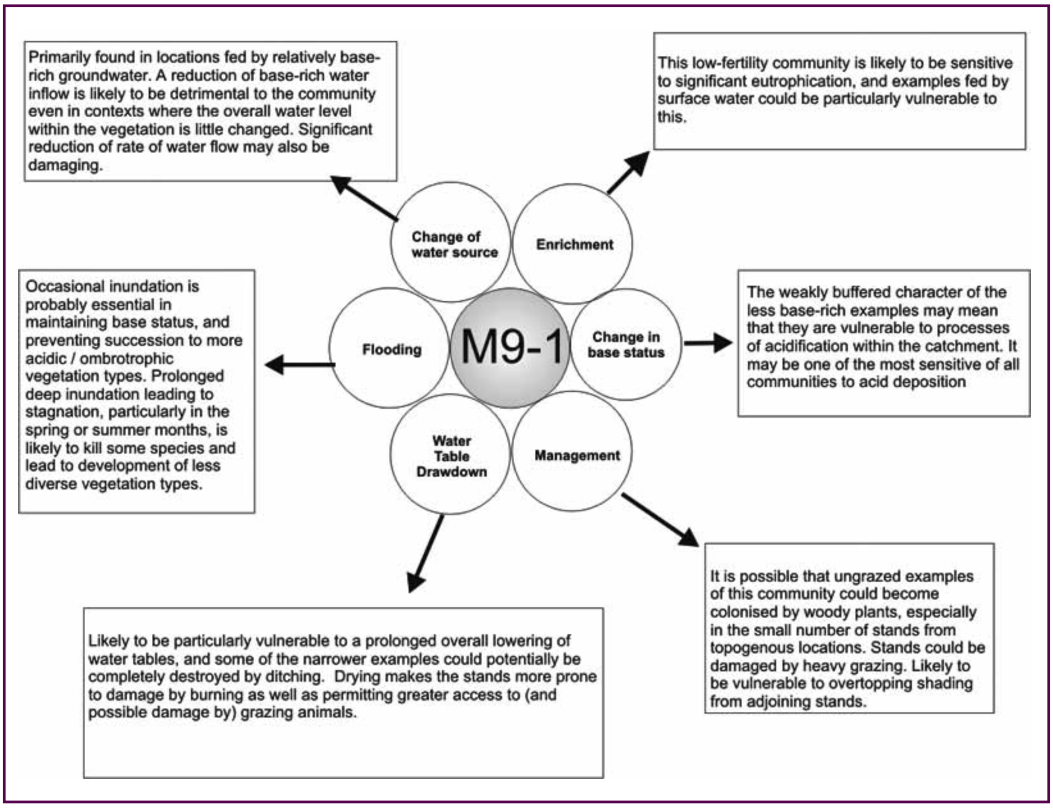
Many examples of this community are potentially exposed to grazing by livestock, but the importance of this in maintaining the character of the vegetation is not known. In most cases, management of examples of M9-1 is inextricably dependent on management of the wider mire habitats in which the stands are embedded. Likewise, seral processes may be dominated by events on adjoining surfaces, and a woodland canopy may be able to overtop examples of M9-1 from shrubs growing alongside the community more readily than scrub can colonise it directly.

## 6.4 Implications for decision making

#### 6.4.1 Vulnerability

Figure 6.3 outlines some of the possible floristic impacts of changes to the stand environment. M9-1 is likely to be particularly vulnerable to a prolonged overall lowering of water tables, and some of the narrower examples could be completely destroyed by ditching. In addition, a reduction of base-rich water inflow is likely to be detrimental to the community, even in contexts where the overall water level within the vegetation is little changed. The weakly buffered character of the less base-rich examples of this community may mean that they are particularly vulnerable to processes of acidification within its catchment, and its specific characteristics suggest that it may be among the most sensitive of all mire communities to acid deposition.

Figure 6.3 The possible effects of environmental change on stands of M9-1



This low-fertility community is likely to be sensitive to eutrophication, and examples fed by surface water could be particularly vulnerable to this. However, many examples are in remote, rough grazing locations that are not obviously subject to a significant eutrophication threat.

It is possible that ungrazed examples of this community could become colonised by woody plants, especially in the small number of stands from topogenous locations. In many of the smaller stands, a bigger seral threat could come from overtopping by woody plants that have colonised unmanaged surfaces adjoining the M9-1 stands.

### 6.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage, and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M9-1 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M9-1 in the short to medium term.
- Prolonged water drawdown, which has resulted in loss of water flow and mineralisation of nutrients from the peat, may require many years to reverse.

### 6.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to M9-1 include the following:

- There are currently no data to better inform the temporal water table characteristics of M9-1 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M9-1 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This is especially the case in locations where the role of groundwater is uncertain and may require detailed ecohydrological investigations at representative sites.
- The relationship of M9-1 to M14 and M29 merits further clarification, along with the possible identification of sub-communities within M9-1.
- Data on the spatial extent of M9-1 are lacking.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

# M9-2 (*Carex diandra* – *Calliergon*) mire

## 7.1 Context

Examples of the M9-2 community have been included in the ‘alkaline fens’ SAC feature, as well as ‘transition mire and quaking bog’ and ‘calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*’.

### 7.1.1 Floristic composition

A vegetation type of rheo-topogenous conditions in mainly lowland locations, which broadly corresponds to the sub-community M9b of Rodwell (1991).

Vegetation is typically species rich, although has a wide range of species per sample (mean 29, range 9–69 species per sample). The community is usually dominated by Cyperaceae (such as *Carex diandra, C. lasiocarpa, C. rostrata* and *Eriophorum angustifolium*), but sometimes with much *Cladium mariscus* or *Phragmites australis*, and usually with a rich variety of associates, most commonly *Potentilla palustris* and *Menyanthes trifoliata*. Bryophytes, mainly ‘brown mosses’ (especially *Calliergon* species and *Drepanocladus revolvens*), are often conspicuous forming a large proportion of the autumn standing crop (Shaw and Wheeler, 1991). Some stands support nationally uncommon or rare fen species such as *Carex appropinquata, C. limosa, Eriophorum gracile, Sphagnum contortum*.

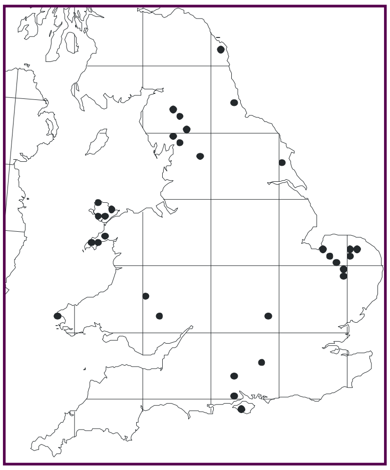
Constant species (from England and Wales) are *Galium palustre*, *Juncus subnodulosus*, *Mentha aquatica*, *Menyanthes trifoliata*, *Potentilla palustris* and the bryophyte *Calliergon cuspidatum*, of which, only *Menyanthes* is similarly constant in M9-1. These species alone indicate some of the floristic differences between the two communities. Other differences include much more *Carex diandra* in M9-2 (73%) than M9-1 (2%); less *C. lasiocarpa* (19% *versus* 27%); much less *Scorpidium scorpioides* (13% *versus* 72%) and more *Calliergon giganteum* (35% *versus* 7%) and, particularly, *C. cuspidatum* (98% *versus* 43%). Sphagna are generally poorly represented in this community, with *Sphagnum subnitens* (4%), *S. palustre* (1%) and *S. contortum* (0.5%).

### 7.1.2 Distribution

Widely distributed in lowland England and Wales (recorded from 37 sites, Figure 7.1), but very scattered; mainly found in the North and West but rare in the South and East. The main centres of distribution are in regions with shallow ground basins irrigated by base-rich water, for example, in some basins in the Carboniferous Limestone and some other deposits in Anglesey and in a few places in North-West England (such as Malham Tarn, Sunbiggin Tarn). The examples from East Anglia are mainly from small ground hollows (pingos) or other basins, including some very small depressions within seepage slopes. Most of these examples are small and fragmented, not in good condition, and the distribution map exaggerates the importance of M9-2 in this region. Some of the best examples of this community occur in the basin mires of the Scottish borders, but these are outwith the compass of the Wetland Framework project.

It is likely that M9-2 was formally more widespread in Eastern England, but it is often difficult to distinguish former occurrences of this vegetation from those of M13 on the basis of past species records, because of shared floristic features. However, there is strong reason to suspect that M9-2 type vegetation once occurred along the margins of some small floodplains, where there were significant groundwater inputs, especially in reflooded turbaries (such as Blo’ Norton Fen (Norfolk), Tuddenham Turf Fen (Suffolk)).

**Figure 7.1 Distribution of M9-2 in England and Wales (from FenBASE database)**



### 7.1.3 Landscape situation and topography

Characteristic of basin mires, including some ground ice hollows. Also associated with natural sumps, reflooded peat pits or even occluded drains within a variety of wetland contexts, including floodplain and valleyhead fens. A few examples occur in tiny depressions embedded within wet soligenous slopes, or around the margins of open water (such as Sunbiggin Tarn, Cumbria).

### 7.1.4 Substratum

In most, except for some partly drained examples, M9-2 forms a soft mat. Sometimes quaking or semi-floating, though the degree of solidity and the depth of fluid peat/water beneath it varies: at East Walton Common (Norfolk), there is about one metre of very fluid material beneath M9-2 rafts; at Great Cressingham Fen (Norfolk) it is about 40 cm. Beneath the upper horizons, peat depth is also variable. In many sites there is only a shallow accumulation of lower peat, but in some of the deeper basins the peat infill is correspondingly deeper. Many of the basins are clearly hydroseral, with lake muds or more frequently, marl at depth. In other sites the peat is underlain by silty sands or sands and gravels; examples at Stockbridge Fen (Hants) are in old turbaries embedded within the complex alluvial infill of the River Test.

Some examples are clearly associated with strongly calcareous rocks (Carboniferous Limestone or Chalk), but others are associated with base-rich Drift (such as Irish Sea Till in Pembrokeshire).

### 7.1.5 Zonation and succession

M9-2 occurs in a variety of contexts and can sometimes be closely associated with other vegetation types (such as M10, M13, M22 and M24). Some examples, such as those in the turbaries of Stockbridge Fen (Hants), are abruptly embedded within alluvial grassland. Even some of the larger examples show little evidence of natural zonations, probably because of drainage initiatives (such as Great Cressingham Fen, Norfolk) or peat extraction. At Cors y Farl (Anglesey), M9-2 occurs as small fragments peripheral to a large area of *Cladium* swamp (S2) which occupies most of the basin. S2 and M9-2 are also juxtaposed at Cors Goch (Anglesey), where in general S2 is in the wettest locations, sometimes around small pools, and flanked by some quite extensive stands of M9-2. In other basin contexts, M9-2 may occupy almost all of the shallow depression (such as Bryn Mwcog, Anglesey) or adjoin, more or less directly, upon open water (such as East Walton Common (Norfolk), Sunbiggin Tarn (Cumbria)), though usually with a narrow band of separating swamp. In only a few of these examples does M9-2 form part of a clearly interpretable hydroseral zonation pattern, due either to the natural vagaries of the sites, or that most of them have been disturbed by past peat extraction (though this is often not obvious). This contrasts with the more consistent hydroseral patterns of M9-2 in some of the basin mires of the Scottish Borders (though many of these also have been dug extensively for peat and marl).

Examination of successional sequences in the underlying horizons of the Border Mires (Tratt, 1998) suggests that M9-2 normally arises hydroserally from a preceding phase of (usually *Carex rostrata* or *Equisetum fluviatile*) swamp, typically as an (~ extensive) buoyant raft. This may be quite persistent or may become colonised by scrub (usually becoming W3) or become invaded by *Sphagnum* and acidify. *Sphagnum* areas may be initiated on particularly buoyant rafts, but mostly these consolidate to form a central zone of acidic fen (M5 and then M4) surrounded by a moat of M9-2 (possibly seen as a proto-lagg). In a few locations, however, there is little evidence for the development of M4 and M5 surfaces, but patches of acidification occur within M9-2, to form a species-rich mosaic of *Sphagnum* hummocks (often with prominent *S. warnstorfii)*, separated by base-rich depressions and pools.

Examples of M9-2 in England and Wales rarely show the clear acidification zonations found in the Border Mires, but elements of the succession can sometimes be found. For example, at Cors Goch (Anglesey) localised acidic surfaces occur within the fen, which have developed as seral innovations from M9-2, probably on buoyant surfaces. In other sites, however (such as Newton Reigny Moss, Cumbria), elevated acidic surfaces associated with M9-2 more often represent the residual baulks left within turbaries. A number of the M9-2 localities in North-West England are in peat workings within former small raised bogs, though in most cases there is little residual ombrogenous surface. It is quite possible that other sites such as Cors Goch may also be former raised bogs in which the ombrogenous peat has been so comprehensively removed that there is no residual stratigraphical evidence for their former status. In some apparently undisturbed basins in the Scottish Borders, M9-2 occupies a narrow lagg around slightly domed rain-fed surfaces.

## 7.2 Supply mechanism and conceptual model

Fifty-nine per cent of samples were identified as occurring within WETMEC 13 (seepage percolation basins, such as Cors Goch (Anglesey), East Walton Common (Norfolk), Newton Reigny Moss (Cumbria)), with 18% within WETMEC 18 (percolation troughs such as Cliburn Moss (Cumbria)) and 9% in WETMEC 20 (percolation basins such as Dowrog Common (Pembrokeshire)). There were a few occurrences within WETMECs 7, 8, 9, 14, and 19.

The majority of examples of M9-2 are in basins that are primarily groundwater-fed. Inputs of rain generated run-off may occur in certain situations, but are probably of little consequence to the summer water balance (though some storage may occur). Two of the stands in East Anglia (Badley Moor and Booton Common) are associated with strongly artesian Chalk aquifers and are effectively depressions embedded within a mainly soligenous system.

Examples of M9-2 associated with Carboniferous Limestone in Ynys Môn (such as Cors Goch, Cors y Farl) appear to be primarily groundwater-fed, though the topography of the basins may mean that high water levels are maintained by constraints on drainage and rainfall, and that the proportionate contribution of groundwater may be much less than in the more soligenous systems. Other examples of this community occur in fen complexes which are undoubtedly fed primarily by groundwater, but where the stands of M9-2 are not necessarily fed by direct groundwater outflow, but are associated with surface water drainage (such as some examples at Malham Tarn, Yorkshire). In some others, surface water supply appears to predominate, though this may be largely groundwater-sourced, as in the case of some examples associated with the St David's Heaths in Pembrokeshire. It is possible that in some high rainfall areas, shallow depressions upon calcareous clays might provide appropriate conditions for the development of M9-2 without significant telluric inflows, other than rain-generated run-off. The majority of stands, however, appear to be essentially rheo-topogenous (that is, topogenous, but with significant lateral water movement), with clear evidence for consistent water throughflow, from whatever telluric source.

There appear to be two mechanisms by which the high, relatively stable water table is maintained (which can operate in combination): (i) a shallow hollow within a permanent seepage face, where the high water table is maintained by soligenous inputs in conjunction with the topography; and (ii) a deeper hollow with a semi-floating raft of vegetation, where the raft has an important water regulation function and where a loose transmissive infill beneath this may facilitate water supply. The rafting mechanism is particularly important in larger topogenous sites on deep peat or marl, where the substratum is of rather low permeability so that significant groundwater inputs are primarily by lateral flow from the mire margins.

Schematic representations of the major water supply mechanisms to M9-2 are indicated in Figure 7.2.

**Figure 7.2 Schematic representation of the major water supply mechanisms to M9-2 (after Wheeler, Shaw and Tanner, 2009)**

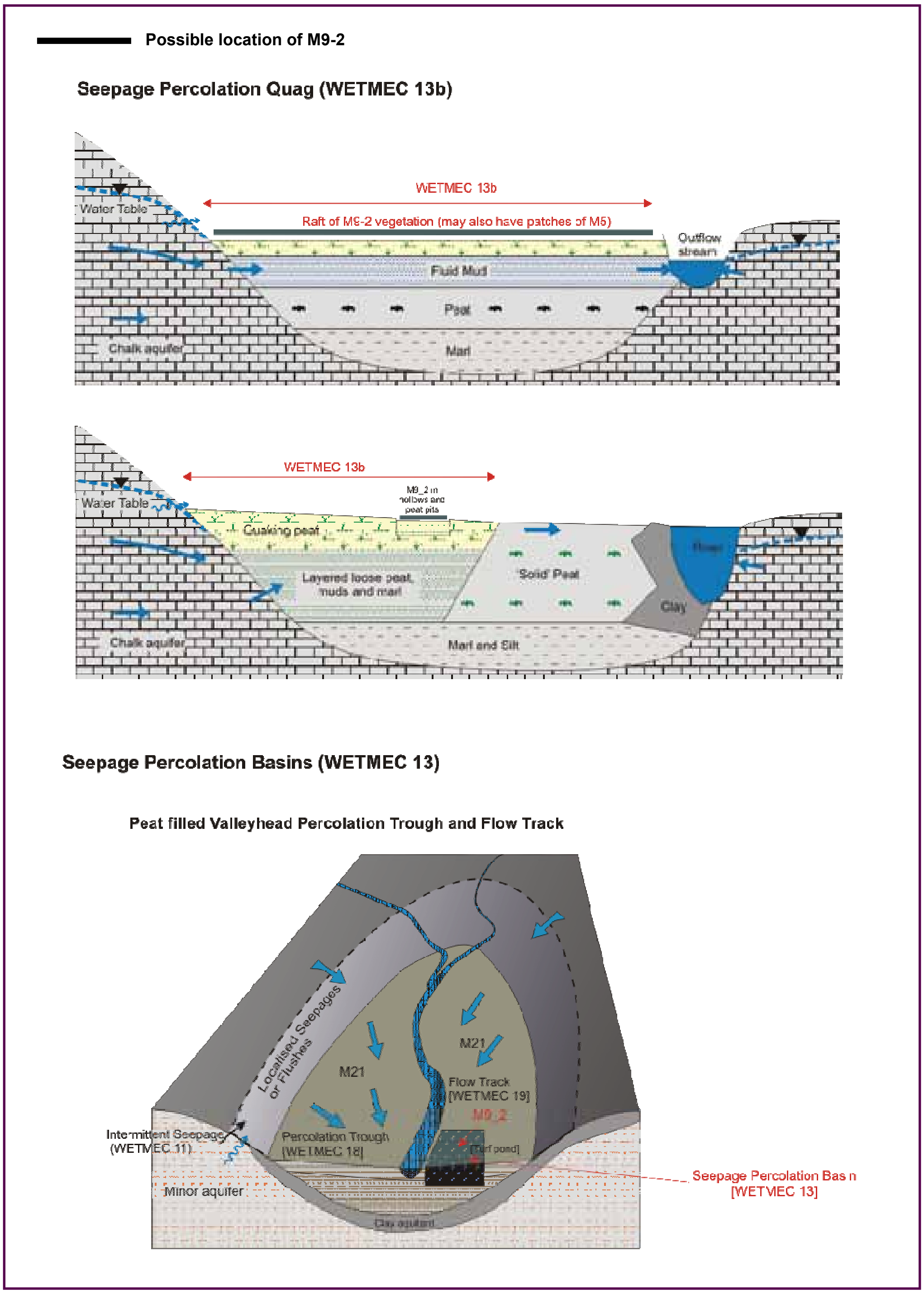
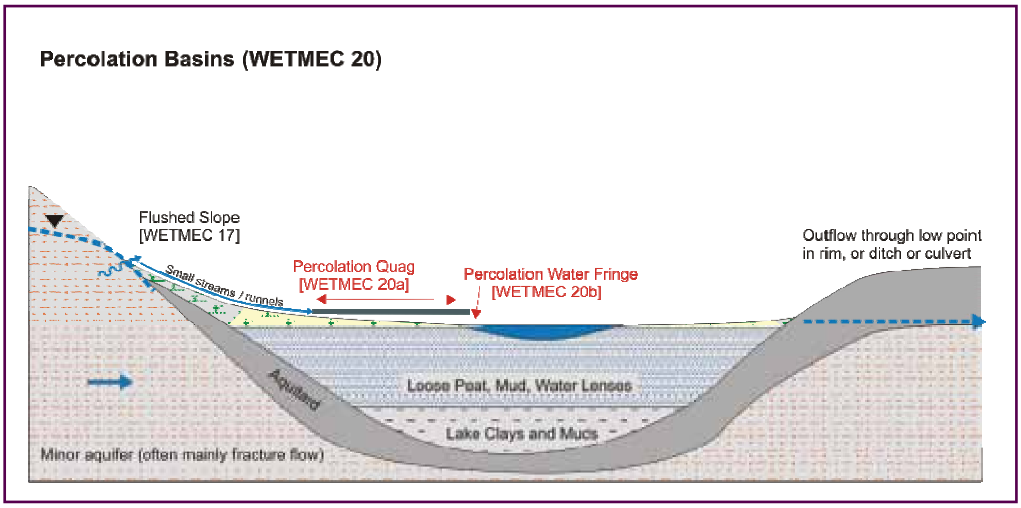


Figure 7.2 (continued)




## 7.3 Regimes

### 7.3.1 Water

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 7.1, together with mean recorded values for summer water table associated with stands of M9-2.

The water table is consistently high beneath M9 stands, usually just above or below the surface, sometimes forming shallow swamp (especially in winter or after heavy rain). The highest water tables are associated with unconsolidated surfaces and are probably, in part, an artefact associated with depression of the vegetation raft during sampling; the lowest water tables are associated with comparatively solid surfaces, which either never had a buoyant vegetation mat or where this has grounded.

Specific time-series data for stands of M9-2 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

#### Optimal water levels

- Typically, consistently at or just above surface level, particularly where forming a floating raft, although some examples may experience considerable fluctuations in water level.
- Association with semi-floating raft or turf pond infill can provide some vertical mobility and comparative hydrological stability.
- In some locations (such as some of the Limestone basins in Anglesey), the community can be exposed to naturally low water tables during occasional summer droughts, though data on the depth and duration of low water tables are not available.

Table 7.1 **Rainfall, potential evaporation and water table data for M9-2**

| | Mean | Min | Max |
|---|---|---|---|
| Rainfall (mm $a^{-1}$) | 1,012 | 646 | 1,679 |
| Potential Evaporation (mm $a^{-1}$) | 565 | 467 | 646 |
| Mean Summer Water Table (cm agl or bgl) | 4.5 | -14 | 24 |

- Some examples of this community seem able to persist in low water conditions, but this is not typical and it cannot be assumed that they are in long-term equilibrium with the drier conditions.

- Occasional flooding of the surface, particularly with base-rich water, may be important in preventing the extensive development of ombrotrophic nuclei and succession to community types associated with more acidic conditions (such as *Carex rostrata Sphagnum squarrosum* mire (M5), *Carex rostrata – Sphagnum recurvum* mire (M4)) and/or invasion by scrub. Buoyant surfaces may be particularly prone to acidification.

#### Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can therefore be speculated that these would lead to a loss of wetland species and increased representation by dryland species. Partial drainage, if accompanied by vegetation management, may lead to an increase in species richness as a form of fen meadow becomes established. Further water drawdown (including grounding of a floating raft) leading to peat drying and subsequent degradation would lead to development of rank fen, rapidly becoming wooded without management.

- Autogenic accumulation of peat can ultimately lead to some form of woodland or, in some sites, *Sphagnum* surfaces; draining may speed the succession to woodland.

- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of less diverse vegetation types, reflecting natural transitions to swamp conditions.

### 7.3.2 Nutrients/hydrochemistry

Typically found in situations of intermediate base status with respect to the main rich and poor-fen communities, although the community covers a wide range. Soil fertility is generally low to moderate (and similar to M9-3, but generally higher than M9-1, and lower than many examples of S27). Figures for pH, conductivity and substratum fertility measured in stands of M9-2 are presented in Table 7.2.

Shaw and Wheeler (1991) found that the variation in water level was relatively small in this community, and apparently of less importance in determining the floristic variation than base status or fertility. The most species-rich stands, and those with most rare fen species, are of very low fertility, and this is almost certainly essential to their optimal development and maintenance of their floristic character. The vegetation may retain its essential floristic composition even in quite enriched conditions, but this may only be a short-term response due to inertia, as the enriched stands tend to have lower species densities and a prominence of eutrophic species such as *Agrostis stolonifera* (Shaw and Wheeler, 1991).

**Table 7.2 pH, conductivity and substratum fertility measured in stands of M9-2**

| Variable | Mean | ±SE | Min | Max |
|---|---|---|---|---|
| Water pH | 6.2 | 0.03 | 5.0 | 8.0 |
| Soil pH | 6.1 | 0.04 | 5.0 | 7.4 |
| Water conductivity (Kcorr µS $cm^{-1}$) | 294 | 1.3 | 70 | 916 |
| Substratum fertility[11] (mg phytometer) | 13.5 | 0.27 | 5 | 39 |

[11] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility ‹ 8 mg, high fertility › 18 mg.

### 7.3.3 Management

The community may be managed, but many examples appear to be floristically relatively stable without management. Many examples are open to grazing livestock, but the wetness of the substratum may mean that stands are infrequently grazed. However, Shaw and Wheeler (1991) found that lightly grazed stands included those with the highest numbers of rare fen species (and principal fen species). It is possible that some stands were once mown for marsh hay, but this is no longer practised.

## 7.4 Implications for decision making

### 7.4.1 Vulnerability

Figure 7.3 outlines some of the possible floristic impacts of changes to the stand environment. As a community of low fertility, wet, topogenous situations, usually of moderate to high base status, it is particularly vulnerable to lowered water tables and eutrophication, although floating rafts may provide some accommodation. Conservation management involves ensuring low fertility, relatively high base status and relatively high water levels. Ongoing terrestrialisation is an eventual threat to many examples, by which a poor-fen surface (with *Sphagnum* development) or a form of woodland (such as *Salix pentandra* – *Carex rostrata* woodland (W3)) may ultimately develop; their conservation may thus require rejuvenation/maintenance of hydroseral conditions (peat excavation).

Eutrophication leads to impoverishment and loss of rare species, with an increased prominence of such species as *Agrostis stolonifera* and *Phragmites australis*, and probable replacement by a more eutrophic vegetation type.

The vulnerability of stands of M9-2 to changes in water supply depends considerably upon the precise water supply mechanism. Where the water level in basins with M9-2 is directly determined by aquifer water tables, vulnerability may be most related to the degree of water level reduction which can be accommodated by rafts before significant grounding and drying occurs, and whether significant grounding is reversible or leaves the community permanently disrupted. In other sites developed over low-permeability deposits (such as marl) and where the water level is potentially controlled by the level of the outfall as well as by rates of water inflow, a reduction of aquifer water tables may not have such a direct effect. In this case, sites and communities may be more vulnerable to increased drainage.

It seems likely that the biggest single cause of loss of this community in East Anglia may have been over-deepening of rivers: this certainly seems to have affected examples formerly located along the upland margin of some small floodplains (such as Blo' Norton Fen, Tuddenham Turf Fen (Norfolk)).

### 7.4.2 Restorability

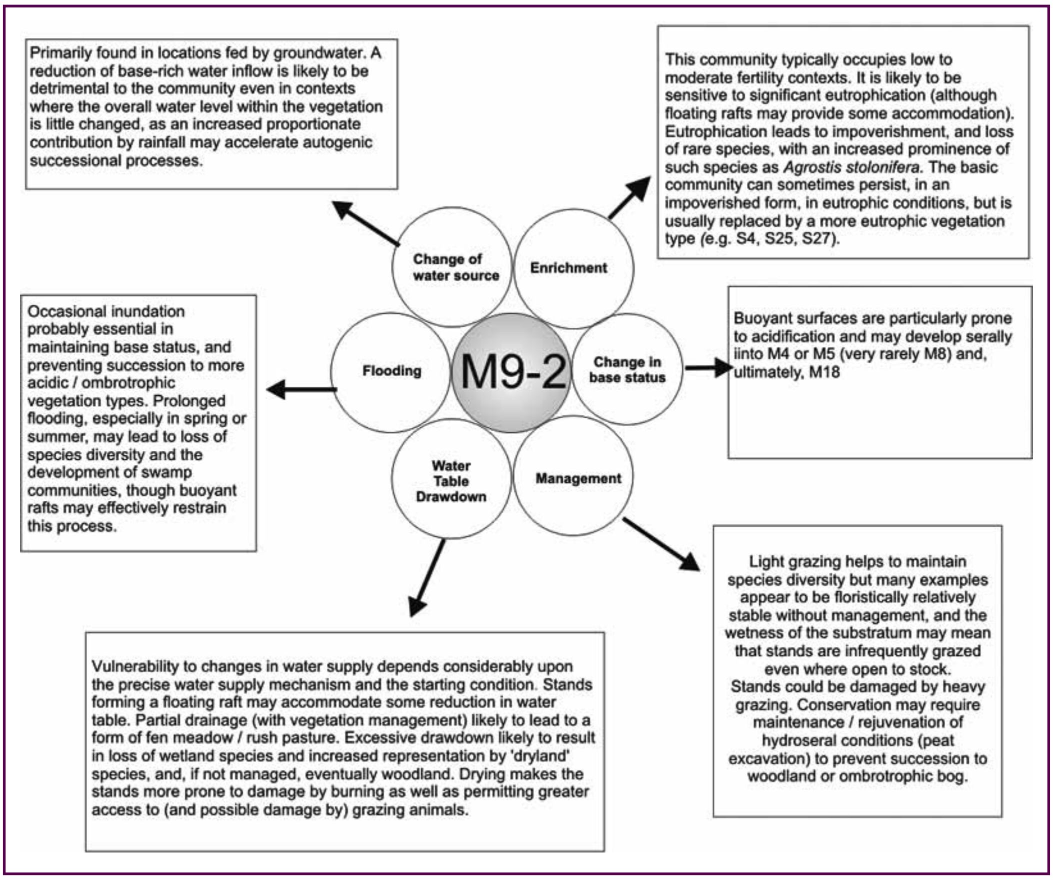
As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M9-2 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M9-2 in the short to medium term.

- Prolonged water drawdown which has resulted in both the grounding of the floating raft, and mineralisation of nutrients from the peat, may require many years and major operations such as peat removal to reverse.

- Many, perhaps most, known examples of M9-2 in lowland England and Wales occupy peat, clay or marl workings. Some of them were undoubtedly dug within rain-fed peat (such as Newton Reigny Moss, Cumbria), others probably just in fen peat (such as Blo' Norton and Thelnetham Fens (Norfolk/ Suffolk)). This artificial origin points to the potential restorability of M9-2, but the conditions which once favoured this are not really known, and may no longer occur.

Figure 7.3 **The possible effects of environmental change on stands of M9-2**




### 7.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to M9-2 include the following:

- There are currently no data to better inform the temporal water table characteristics of M9-2 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M9-2 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of M9-2 are lacking.
- Some samples of M9-2 vegetation show much floristic overlap with samples of S27. It would be useful to clarify the relationship between these two units. Preliminary examination suggests that there may not be any obvious discontinuity between the two types, in which case the identification of an arbitrary boundary would be helpful, providing it could be defined and recognised.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

# M9-3 (*Carex diandra – Peucedanum palustre*) mire

## 8.1 Context

Examples of M9-3 have been included within the 'calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*' SAC interest feature.

### 8.1.1 Floristic composition

A rare herbaceous fen community, apparently confined to Broadland, that is characteristically species-rich (mean 33, range 28–42 species per sample; Table 8.1) with an abundance of small sedges and brown mosses. *Carex diandra* and *C. lasiocarpa* are often both prominent, but the main dominant species is *Cladium mariscus*. M9-3 is particularly notable for supporting populations of the internationally rare fen orchid (*Liparis loeselii*) in Broadland, and supporting a particularly high (10) mean number of rare species per sample, including *Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Cicuta virosa, Cladium mariscus, Dactylorhiza praetermissa, Epipactis palustris, Liparis loeselii, Oenanthe lachenalii, Peucedanum palustre, Ranunculus lingua, Rhizomnium pseudopunctatum, Stellaria palustris, Thelypteris palustris, Utricularia intermedia*. The community is floristically transitional between M9 and S24 and is not adequately represented by the NVC.

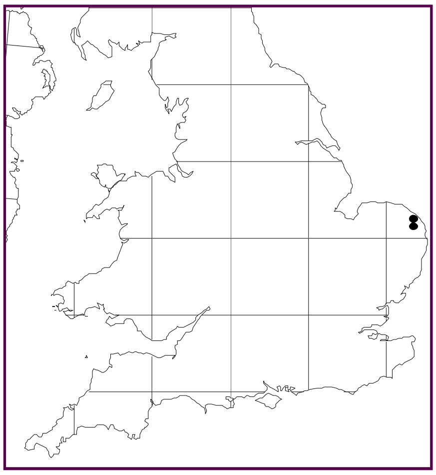
### 8.1.2 Distribution

The community is confined to Broadland (Figure 8.1) where, currently, it occupies the valleys of the Ant (Broad Fen (Dilham), Sutton Broad and Catfield Fen) and Bure (Woodbastwick Fen, Ranworth Broad and Upton Fen). There are former records for what appears to have been this community from Decoy Carr (Acle), Strumpshaw Fen and Shallam Dyke. Stands of S24 that have strong floristic affinities to this unit are more widespread in Broadland than M9-3, but are often developed only as fragments.

### 8.1.3 Landscape situation and topography

All examples of M9-3 occur in floodplain fens. Stands are usually localised with many located close to the upland margin of the fen, but stands at Woodbastwick

**Figure 8.1 Distribution of M9-3 in England and Wales (from FenBASE database)**

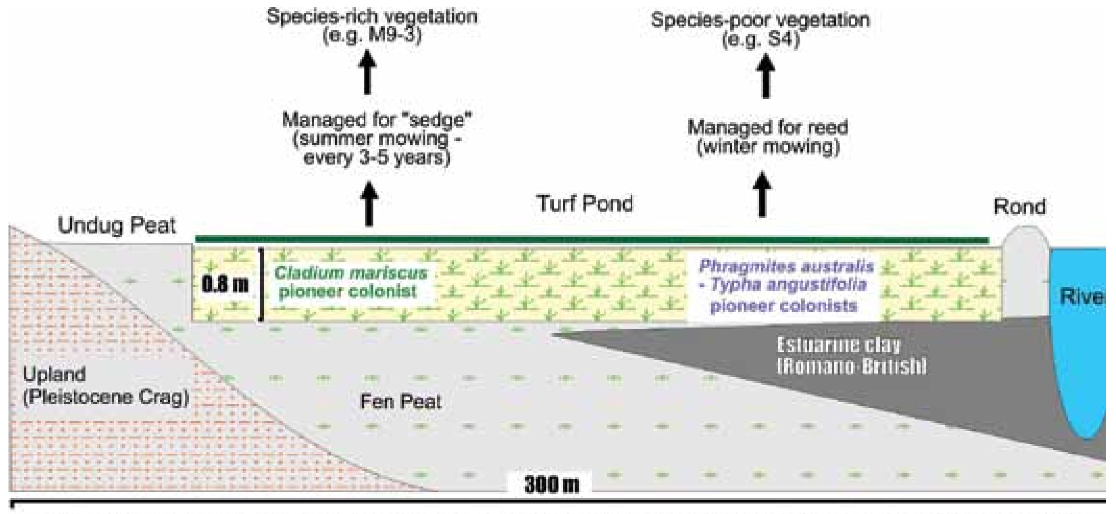


(and some former stands elsewhere) are located deep within the fens. Most occur as isolated stands, but at Sutton Broad they form a (mostly narrow and discontinuous) zone along much of the upland margin.

### 8.1.4 Substratum

All of the stands occupy parts of re-flooded peat workings, either deep medieval excavations (the Broads) or shallower eighteenth to nineteenth century turf ponds, where they form a quaking, hydroseral mat. In a few stands the peat has been removed almost to the underlying mineral ground (Sutton Broad), but in most cases there is some two to five metres of peat (mostly dense brushwood peat) below the floor of the peat cutting. In some, perhaps most, sites (such as Great Fen, Catfield) the peat is separated from the underlying Crag by a layer of soft grey clay. As is reflected in the relatively low values of water conductivity (see below), in no known cases is the peat cutting underlain by estuarine clay of the Romano-British transgressive overlap (turf ponds underlain by estuarine clay support a quite different vegetation, normally dominated by *Phragmites australis* or *Typha angustifolia*, as illustrated in Figure 8.2).

**Figure 8.2 Schematic diagram of recolonisation of reflooded, shallow turf ponds in Broadland (after Wheeler, Shaw and Tanner, 2009)**




*Phragmites australis* and *Typha angustifolia* are the usual primary recolonists where the turf pond is floored with estuarine clay, but *Cladium mariscus* is often the main recolonist over continuous fen peat. The identity of the initial colonist species appears to determine the subsequent management and species richness of these different parts of turf ponds, although, *Cladium* sometimes invades the reedbeds at a later phase of the successional process.

### 8.1.5 Zonation and succession

Most examples occupy turf ponds embedded within un-dug fen, tending to adjoin more extensive surfaces of solid peat. As such, M9-3 can be proximate to various drier communities, but mainly to examples of S24.

Within individual turf ponds on continuous peat, there is only occasionally a clear spatial zonation: instead, M9-3 usually occurs in a patchwork, juxtaposed with wetter (for example, S2), drier (for example, S24) and, sometimes, more acidic (for example, *Betulo-Dryopteridetum cristatae*) surfaces, apparently representing a patchwork of different stages of terrestrialisation.

In locations where a turf pond is located partly over Romano-British estuarine deposits and partly over continuous peat (such as Great Fen, Catfield), a clear zonation can sometimes be observed with reed-dominated vegetation (S4 or S24) over the clay grading into *Cladium*-dominated vegetation (including M9-3) over the continuous peat (see Figure 8.2).

Sutton Broad is considerably deeper than the nineteenth century turf ponds and has a clear hydroseral gradient from open water through reedswamp to fen. At this site M9-3 does show a clear zonation, occurring as a discontinuous band close to the upland margin, and bordered on the drier side by fen meadow (M22) or fen carr.

Investigations of underlying organic horizons (Giller and Wheeler, 1986, 1988) have shown that M9-3 may have developed in turf ponds from a preceding wetter phase (typically *Cladium* swamp). In some locations M9-3 persists to the present day, but in others it has clearly been replaced serally by a less diverse vegetation (either S24, W2 or locally, acidic fen surfaces). The specific triggers to acidification are not well understood, and it is not clear if this is likely to be a pervasive or just local late-successional development of the M9-3 community.

## 8.2 Supply mechanism and conceptual model

Figure 8.3 illustrates the major water supply mechanisms to the M9-3 community. Most examples are restricted to percolating fens fed by surface water or groundwater: most samples (74%) were identified as occurring within WETMEC 6 (surface water percolation floodplains such as Catfield Fen), with 22% in WETMEC 13 (seepage percolation basins such as Upton Fen). Only one example (an old record from East Ruston Common) occurred in WETMEC 9 (groundwater-fed bottoms).

The identity of the main water sources to stands of M9-3 has attracted some attention (for example, Van Wirdum *et al.*, 1997), although it appears that, providing the water is fairly base-rich but not rich in nutrients or sea salts, its exact provenance is unimportant. In most stands, telluric water is supplied by lateral flow through very loose peat beneath the quaking mat from nearby sources such as feeder dykes, at least during low water conditions.

The factors responsible for the localisation of M9-3 in peat cuttings in Broadland are not really known, especially as the potentially convenient explanation of localised groundwater upflow does not appear to be valid. Restriction of M9-3 to turbaries beyond the limit of estuarine clay, however this is caused, helps to account for much of the macro-distribution of the community, but even with this constraint the community does not necessarily occur in all locations which would appear to be suitable for it. It is possible that this discrepancy could result from historical management events, coupled with the vagaries of recolonisation by appropriate species (for example in the Berry Hall Fens, or parts of the Catfield fens distant from the river, it is possible that past drainage may have not been conducive to the subsequent establishment of M9-3).

## 8.3 Regimes

### 8.3.1 Water

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 8.1, together with mean recorded values for summer water table associated with stands of M9-3.

Summer water tables do not show much variation between stands, and are consistently near or at the fen surface. However, the microtopographical variation found within most stands makes the specification of a mean water table difficult and potentially misleading.

In many stands, it is possible to find hollows with standing water in the summer and low hummocks/ tussocks (less than 20 cm) above the water level. Indeed, the variation in conditions combines to provide a complex of microhabitats that contributes greatly to the species diversity of high-grade stands. The semi-floating nature of turf pond infill gives the fen surface a degree of vertical mobility and hence hydrological stability (though in winter and spring, sites with river connections can become inundated).

Specific time-series data for stands of M9-3 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

#### Optimal Water Regime

- Most often associated with a mean water table at or near the surface all year round. Its confinement to quaking or buoyant turf pond infill may provide some vertical mobility and thus hydrological stability. The loose peat, and semi-fluid material below the vegetation mat, may provide significant storage and facilitate sub-irrigation with water from adjoining dykes.
- Episodic flooding, including relatively deep inundation, may occur in the winter – and occasionally summer – at river connected sites.

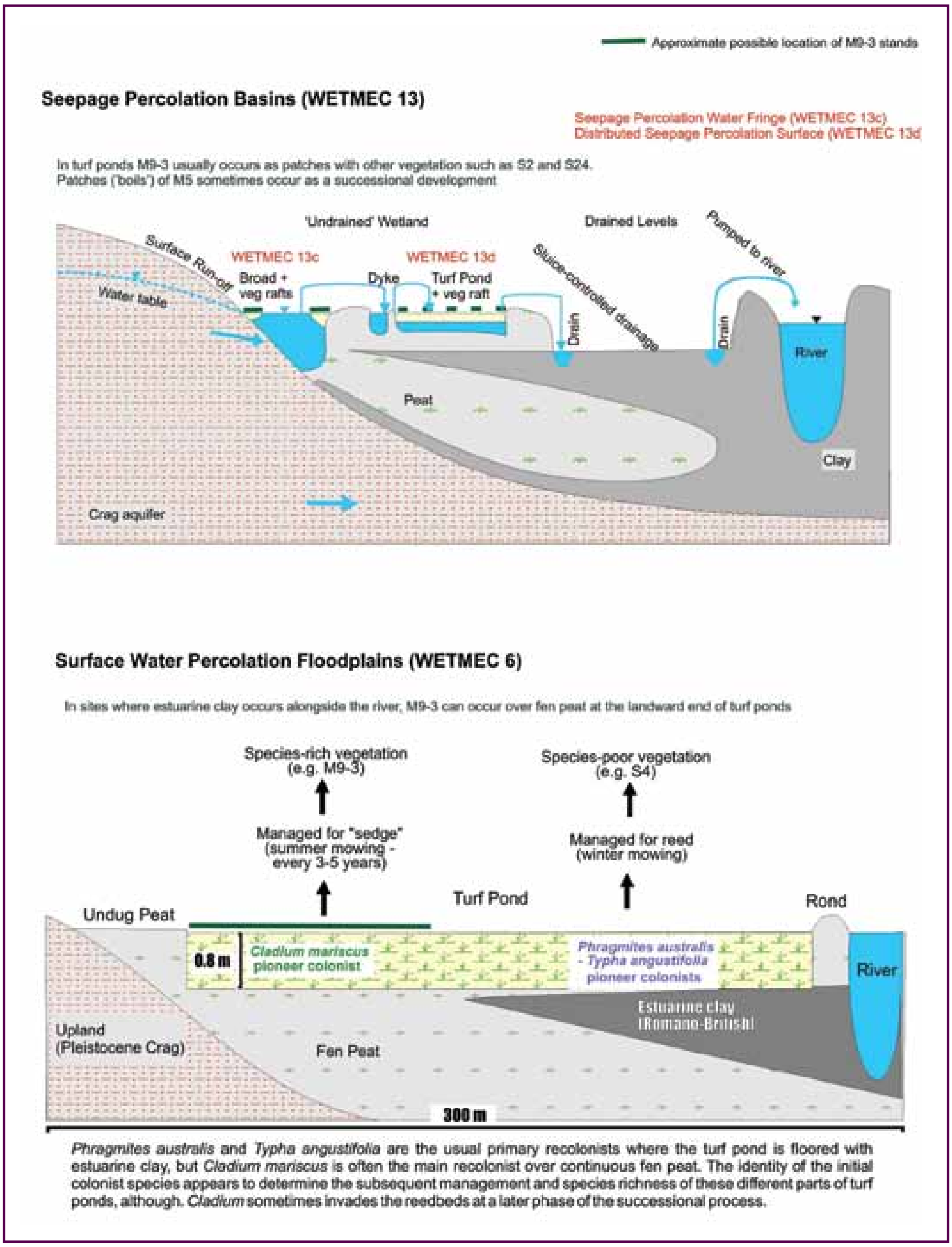
#### Sub-optimal or damaging water regime

- Persistent deep inundation in the summer months is likely to lead to the development of less diverse swamp communities.
- Low sub-surface water tables (except as a consequence of natural microtopographical variation) are not generally a feature of the community and tolerance of protracted water table drawdown is probably very limited. Consolidation, elevation and some drying of the surface can occur serally and are associated with the gradual loss of M9-3 vegetation.

**Table 8.1 Rainfall, potential evaporation and water table data for M9-3**

| | Mean | Min | Max |
|---|---|---|---|
| Rainfall (mm $a^{-1}$) | 611 | 604 | 616 |
| Potential Evaporation (mm $a^{-1}$) | 625 | 625 | 625 |
| Mean Summer Water Table (cm agl or bgl) | -7.3 | -26.2 | 3.2 |

Figure 8.3 Schematic representation of the major water supply mechanisms to M9-3 (after Wheeler, Shaw and Tanner, 2009)



### 8.3.2 Nutrients/hydrochemistry

The substratum (fen mat) is always of low fertility (oligotrophic or low mesotrophic). This contrasts with the mats over estuarine clay which are normally mesotrophic or eutrophic and which support other vegetation types. Where M9-3 occurs close to a eutrophic river, as is sometimes the case, it is presumed that the river water does not significantly penetrate or flood the stand, that any flood water does not have high nutrient loading or much entrained sediment, or that a process of nutrient-stripping is operating.

Mean water pH is 6.4, which is below the threshold at which calcite precipitation can occur. Highest pH values have been measured at Upton Fen, where some biogenic calcite precipitation has been observed in fen pools (which generally have pH values some 0.5 units higher than within the fen mat).

The pH, conductivity and substratum fertility measured in Broadland stands of M9-3 are given in Table 8.2 below.

Wheeler and Shaw (1991) report a mean increment (April to September) in dry weight of above ground standing crop of only 299 g dry wt $m^{-2}$, which reflects the low substratum fertility.

### 8.3.3 Management

Management is necessary for the long-term persistence of the community, but it can withstand several years of dereliction without serious floristic consequences (probably because of the low substratum fertility). Some stands are dominated by *Cladium mariscus* and are mown for sedge (such as Catfield Fen), whilst others receive rather little management or are mown specifically for conservation objectives. An example of M9-3 at Sutton Broad was formerly managed by occasional burning, which helped suppress development of scrub and was not obviously detrimental to the herbaceous vegetation (it may even have been beneficial to a population of *Liparis loeselii*). M9-3 stands are prone to scrub invasion where management is abandoned for long time periods.

## 8.4 Implications for decision making

### 8.4.1 Vulnerability

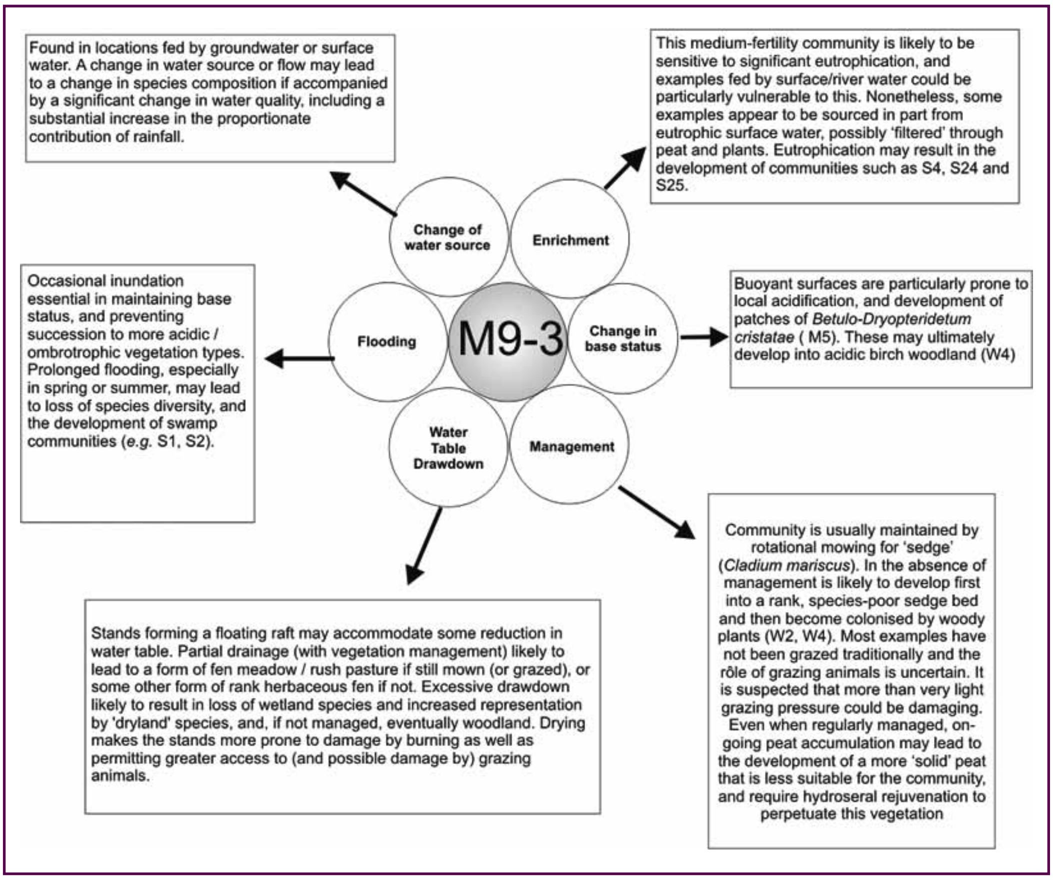
Figure 8.4 outlines some of the possible floristic impacts of changes to the stand environment. Conservation management involves ensuring low fertility and relatively base-rich conditions, periodic vegetation management (summer mowing), and (ultimately) maintenance of hydroseral conditions (peat excavation).

**Table 8.2 pH, conductivity and substratum fertility measured in stands of M9-3**

| Variable | Mean | ±SE | Min | Max |
|---|---|---|---|---|
| Water pH | 6.4 | 0.17 | 6.2 | 6.8 |
| Soil pH | 6.6 | 0.36 | 6.3 | 7.3 |
| Water conductivity (Kcorr µS $cm^{-1}$) | 676 | 197 | 486 | 1,067 |
| Substratum fertility[12] (mg phytometer) | 6.5 | 1.81 | 5.0 | 10.0 |

[12] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility < 8 mg, high fertility > 18 mg.

Figure 8.4 The possible effects of environmental change on stands of M9-3




### Terrestrialisation

M9-3 represents a transient phase of the terrestrialisation of turf ponds or deeper peat diggings, which is manifest in two ways: (i) elevation of the surface by growth of hummock/tussock-forming species and accumulation of decomposing litter; and (ii) accumulation of sub-surface material. The rate of the first of these processes can be considerably reduced by regular mowing (and removal of the mown material); the rate of the second is much less affected by this. Continued growth of rooting structures and formation and consolidation of peat is likely to be detrimental to the water supply mechanism for this vegetation, where it results in a reduction of the vertical mobility of the quaking mat and of the transmissivity of the peat infill. Sub-surface organic horizon data indicates that M9-3 can gradually dry out and become similar to the less rich vegetation of uncut peat surfaces. Conservation of this vegetation type may therefore ultimately require rejuvenation of hydroseral conditions (re-excavation of turf ponds).

### Acidification

Acidification is sometimes an eventual outcome of terrestrialisation, which occurs when the fen mat ceases to be inundated by base-rich water, but remains sufficiently wet to support *Sphagnum* species. Acidification often occurs on buoyant fen mats and can therefore occur at an earlier stage in the terrestrialisation process than changes induced by substratum solidification. Acidification is extremely localised in examples of M9-3 that are periodically inundated by river water (for example, a few patches are known at Catfield Fen) but is prevalent at Upton Fen where there is little surface flooding by telluric water.

### Nutrient enrichment

The low fertilities typically associated with M9-3 mean that stands are potentially vulnerable to nutrient enrichment, especially those partly irrigated by river water. In general, there is little evidence for current detrimental enrichment from river sources, either because nutrients are stripped from the water during summer sub-irrigation or because winter floodwaters are dilute. However, the M9-3 at Sutton Broad is separated from the river by a rather narrow band of reed that may offer only limited protection from penetration by river water. The possible interaction between sub-surface transmission of river water against any groundwater inputs at this site is not known, but could be important in regulating the ingress of enriched surface water into M9-3 stands.

**Groundwater abstraction**

The impact of groundwater abstraction on this community is difficult to predict with present information.

- For many sites the importance of groundwater, if any, to the maintenance of the summer water table is not known, especially where supply appears to be indirect.
- In river-connected sites, other water sources may be able to compensate for any reduction of groundwater inputs, though such sources will only be suitable for the community if they are naturally nutrient-poor or if nutrients are stripped from them by passage through the peat/rhizome mixture (direct input of river water via dykes would be damaging).
- Even in sites which are exclusively groundwater-fed, a small reduction in water level can probably be mitigated by a compensatory movement of the peat mat.

### 8.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M9-3 stands, but the following observations can be made:

- To perpetuate M9-3 in Broadland, it is likely to be necessary to provide new or re-excavated turf ponds to maintain appropriate hydroseral conditions. However, the potential for restoring M9-3 and appropriate starting conditions is largely unknown, though there is no doubt that past turf ponds have become colonised spontaneously with M9-3 vegetation.
- Scrub removal and re-instatement of vegetation management may help to temporarily restore M9-3 vegetation that has been left unmanaged for a while.

### 8.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to M9-3 include the following:

- The information presented here is based on knowledge of wetland sites supporting M9-3 in Broadland (to which region this community is confined).
- There are currently virtually no hydrometric data to better describe the temporal water table characteristics of M9-3 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions about the vulnerability of M9-3 stands to water resource management and water quality in the wider environment it will be necessary, on a site specific basis, to investigate the key water supply mechanisms to M9-3 stands and to establish the relative importance of groundwater versus land drainage water and river water.
- Data on the areal extent of M9-3 appear to be lacking.
- The potential for restoring M9-3 is largely untested (although some trials have begun).
- It would be desirable to clarify the relationships between M9-3, M9-2 and S27.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

# M10 (*Pinguicula vulgaris – Carex dioica*) mire

## 9.1 Context

Examples of the M10 community have been included within the 'alkaline fens' SAC interest feature.

### 9.1.1 Floristic composition

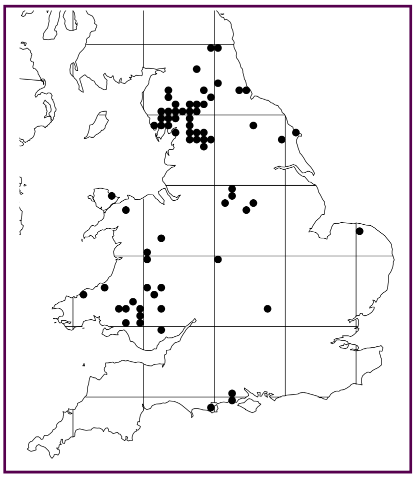
M10 is a mostly low-growing vegetation with an open sward, typically dominated by low-growing monocotyledons (mainly sedges), but including *Schoenus nigricans* at some sites. *Molinia* and/or rushes are sometimes prominent; there is often an extensive bryophyte component and a wide range of associated short herbs. Much of the considerable floristic variation of M10 lies outwith the scope of the Wetland Framework, which has been largely restricted to lowland sites. A total of 264 species were recorded in samples of M10 (Mean = 32; Range = 10–55). The community is particularly important in supporting several rare and uncommon fen species including *Bartsia alpina, Blysmus compressus, Calliergon giganteum, Calliergon sarmentosum, Carex dioica, Dactylorhiza traunsteineri, Drosera intermedia, Drosera longifolia, Eleocharis uniglumis, Epipactis palustris, Equisetum variegatum, Eriophorum latifolium, Euphrasia pseudokerneri, Homalothecium nitens, Juncus alpinoarticulatus, Kobresia simpliciuscula, Moerckia hibernica, Philonotis calcarea, Pinguicula lusitanica, Plagiomnium elatum, Preissia quadrata, Primula farinosa, Rhizomnium pseudopunctatum, Saxifraga aizoides, Selaginella selaginoides, Sphagnum contortum, Sphagnum subsecundum, Sphagnum warnstorfii, Thuidium deliculatum, Tofieldia pusilla, Utricularia intermedia* and *Utricularia minor.* It is notable that some of these have a northern distribution that are otherwise rather rare in England and Wales (such as *Carex dioica, Primula farinosa*).

Rodwell (1991) recognised three sub-communities of M10: *Carex demissa – Juncus bulbosus/kochii* (M10a); *Briza media – Primula farinosa* (M10b) and *Gymnostomum recurvirostrum* (M10c).

### 9.1.2 Distribution

M10 is a very widespread community recorded from 121 sites, mainly in Western, Northern and upland Britain, although some records have been made in the South. The distribution of M10 in lowland England and Wales is shown in Figure 9.1.

**Figure 9.1 Distribution of M10 in lowland England and Wales (from FenBASE database)**



### 9.1.3 Landscape situation and topography

In the lowlands the community forms small stands in isolated locations, often within sloping pastures, but sometimes within heath or woodland or flanked by more acidic peat. M10 often forms a small elongated zone below springs and flush-lines, although larger aggregated flushed slopes supporting this community can also occur. Occasionally found along the sloping margins of topogenous fens (basins or channels such as Sunbiggin Tarn (Cumbria), Malham Tarn (Yorkshire)).

The stands are usually open, often with muddy depressions and runnels separating turfy hummocks and providing a range of micro-habitats.

### 9.1.4 Substratum

Associated with a wide range of soils, but typically on shallow (sometimes skeletal), flushed organic or mineral soils where there is little or no stagnation. Peat, if present, is usually less than 50 cm deep and strongly decomposed and humified. Water flow may constrain the accumulation of organic material and in some instances may remove it by scouring. The turfy hummock – runnel microtopography may be a product of flow processes and poaching by grazing animals.

M10 is usually associated with a calcareous water supply with some examples of marl or tufa having precipitated spontaneously or biogenically. Some examples contain well developed tufa mounds (Tarn Moor, Sunbiggin), although such mounds may arise in association with M10 stands, they do not always support M10.

### 9.1.5 Zonation and succession

Many examples of M10 occur in localised, discrete groundwater-fed locations that may not conform with surrounding habitats, in some cases including other mire habitats. M10 surfaces can therefore show an abrupt transition to a number of adjoining habitats and vegetation types. In some instances, the transition between the M10 stands and drier conditions is marked by a zone of *Molinia*-dominance (such as M24 or M25) or of fen meadow (such as M23). Drier conditions sometimes occur downslope of M10 stands, as well as alongside or above it, but the community may grade downslope into various types of (usually) rheo-topogenous mire, and merge into communities such as M9-1, M9-2, M29, S10, and S27. Some examples of M10 occur within more acidic peaty habitats, sometimes occupying localised patches of base enrichment. Examples of the community have been recorded embedded within stands of M15, M17, M19 and M21. The small number of examples recorded from soakways may show transitions to M9-1 or M29, and can be difficult to distinguish from these.

## 9.2 Supply mechanism and conceptual model

M10 is largely confined to soligenous slopes fed by groundwater from semi-confined or unconfined bedrock or drift aquifers, either directly (as seepages) or by downslope flow of groundwater over an (often) superficial aquitard (flushes). A few examples occur in base-rich water tracks and soakways, but these tend to be transitional to either M9-1 or M29.

Fifty-seven per cent of M10 samples were found to occur within WETMEC 10 (permanent seepage slopes, such as Pont y Spig (Monmouth), Crosby Gill (Cumbria)), with 29% within WETMEC 17 (groundwater flushed slopes, such as Acres Down (New Forest), Banc y Mwldan (Cardigan)). The remainder (10% and 5% respectively) occurred within WETMEC 15 (seepage flow tracks such as Widden Bottom (New Forest) and WETMEC 19 (flow tracks such as Knott End Moss (Cumbria)). The main water supply mechanisms are illustrated schematically in Figure 9.2.

## 9.3 Regimes

### 9.3.1 Water

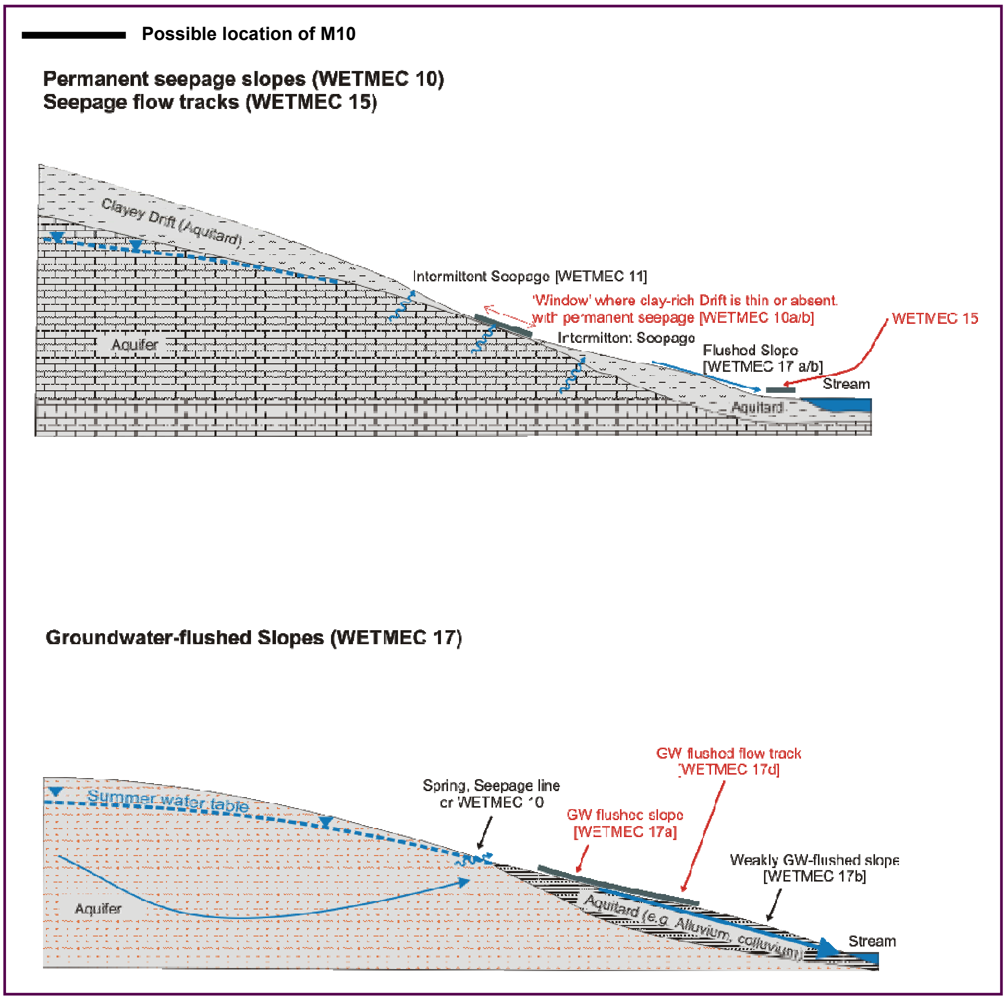
M10 is most commonly found in the cool and wet climate of the North-West, where high annual rainfall and number of wet days help to maintain the conditions of constant flushing. The community tends to be replaced by M13 in the warmer and drier South and East.

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 9.1, together with mean recorded values for summer water table associated with stands.

## Table 9.1 Rainfall, potential evaporation and water table data for M10

| | Mean | Min | Max |
|---|---|---|---|
| Rainfall (mm a-1) | 1,182 | 627 | 1,831 |
| Potential Evaporation (mm a-1) | 539 | 462 | 614 |
| Mean Summer Water Table (cm agl or bgl) | -1.5 | -16.2 | +3.4 |

## Figure 9.2 Schematic representation of the major water supply mechanisms to M10 (after Wheeler, Shaw and Tanner, 2009)




The varied microtopography, and effects of poaching and water-scour, generates subtle but ecologically significant differences in water regime, providing a complex of microhabitats that contribute to the high species diversity of M10. Consequently, mean water table values have limited value, are potentially misleading and should be interpreted with caution.

Specific time-series data for stands of M10 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

### Optimal water levels

- Summer water tables are mostly at or very close to the fen surface (-5 to +1 cm). Only 15% of examples measured had summer water tables of more than 5 cm bgl. A seasonally sub-surface water table may be the natural condition of stands occupying intermittent seepages or fed by groundwater sourced from fractures with short flow paths.

- Flushing by groundwater discharge is a feature of most high grade M10 sites. Slopes generally prevent surface accumulation of water except in small, shallow pools likely to experience high water throughput. Stagnant conditions have not been encountered, even in the wettest examples of the community.

- The normal range of winter water tables is not well known, but in many sites in wetter regions is probably not much higher than summer water tables, on account of the slope.

- The varied microtopography provides a wide range of ecological niches; for example, calcifuge species (for example, *Erica tetralix, Carex demissa*) can occur raised above the level of direct irrigation, whilst species such as *Utricularia minor* and *Eleocharis multicaulis* are found in areas of higher water tables.

### Sub-optimal or damaging water levels

- Whilst shallow pools and runnels are a natural feature, strong flushing and scouring can cause erosional damage (the extent of resultant species loss is however unknown). Widespread inundation, particularly in the summer, is likely to be damaging, but is unlikely to occur in most locations because of their sloping character.

- A seasonally sub-surface water table may be the natural condition of some stands.

- A long-term reduction of the summer water table beneath high quality stands of M10, to the extent that water no longer oozes underfoot in a non-drought summer, may result in some loss of botanical interest. The response of M10 to prolonged drying may be similar to that observed for M13, but no comparable data are available for M10.

### 9.3.2 Nutrients/hydrochemistry

Table 9.2 presents figures for pH, conductivity and substratum fertility measured in stands of M10. The community is typically found in conditions of high base status but low fertility associated with groundwater discharge from calcareous bedrocks and Drift (particularly Carboniferous Limestone in Northern England and parts of Wales). In Wales, some examples are fed from calcareous faces of Old Red Sandstone.

M10 tends to occur in locations of lower fertility and base-status than M13, but the differences are small and there is much overlap between these communities. Some lower pH examples of M10 occur which were not sampled, so that the mean pH is likely to be lower than that found within the samples examined. Research has shown that increases in base richness are associated with an increase in the number of rare species, although fewer rare species were found in the most fertile stands.

**Table 9.2 pH, conductivity and substratum fertility measured in stands of M10**

| Variable | Mean | ±SE | Min | Max |
|---|---|---|---|---|
| Water pH | 6.7 | 0.03 | 4.9 | 7.7 |
| Soil pH | 6.6 | 0.04 | 4.4 | 7.6 |
| Water conductivity (Kcorr μS $cm^{-1}$) | 399 | 1.3 | 101 | 875 |
| Substratum fertility[13] (mg phytometer) | 6.5 | 0.18 | 3 | 18 |

[13] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility ‹ 8 mg, high fertility › 18 mg.

### 9.3.3 Management

Conservation management involves ensuring conditions are wet, flushed, of low fertility and base-rich, with at least occasional management.

Most M10 sites are grazed or have a history of grazing. Grazing is likely to be necessary for maintenance but it need only be light, and some examples may possibly be self maintaining. The presence of a mosaic of stable and disturbed areas supporting different species may increase species diversity, although very heavy grazing may be detrimental.

## 9.4 Implications for decision making

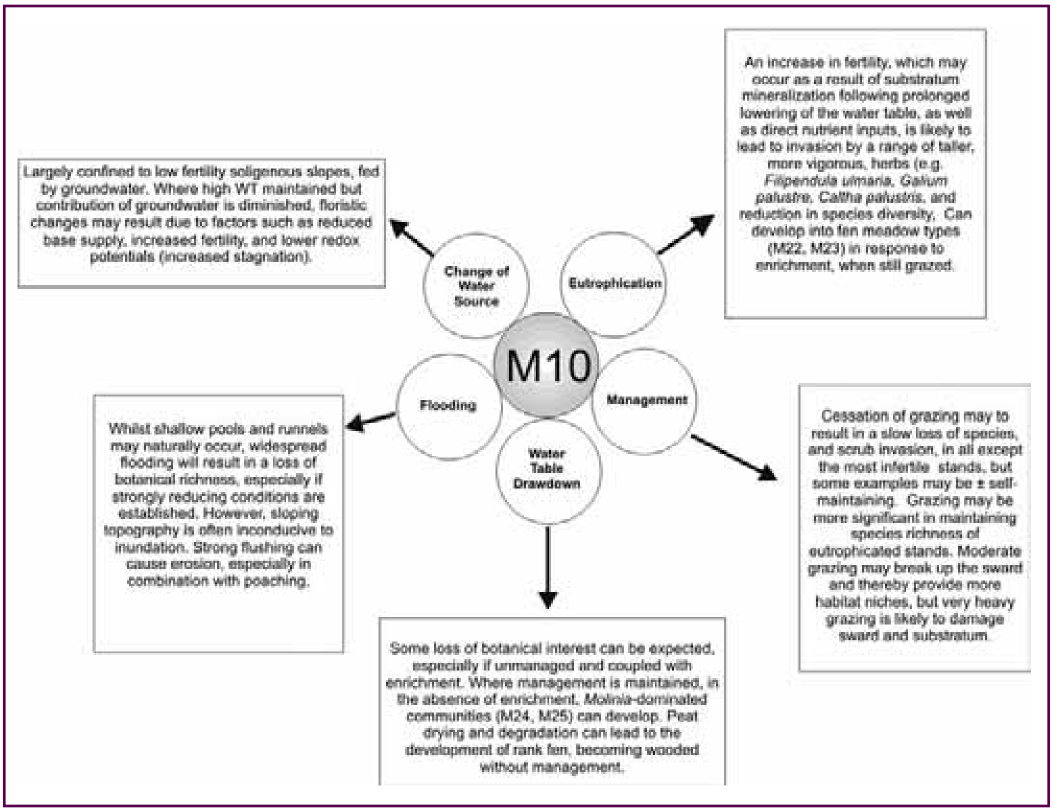
### 9.4.1 Vulnerability

Threats to M10 are similar to M13 however M10 is less likely to experience lower summer water tables than M13. There are however concerns about lowering groundwater tables (associated with nearby quarrying operations, for example, Cwm Cadlan). Examples of M10 in the drier parts of its range on Carboniferous Limestone may experience a higher frequency and severity of natural drought than groundwater-fed slopes on some other aquifers (due to the variable and local spring flows associated with Carboniferous Limestone).

Most M10 sites are surrounded by rough pasture, moorland or low-intensity grassland, and unlikely to be threatened by substantial enrichment. However, some examples are adjacent to improved pasture or arable land (such as Hulam Fen, Durham) and may be threatened by eutrophication.

M10 can maintain its character without grazing for a considerable period, likely due to low fertility and high water tables. Ultimately, the absence of management will cause gradual species impoverishment, especially where there is enrichment. However in sites (such as Widdybank Pastures, Durham) where low fertility is accompanied by a harsh climate, M10 vegetation seems stable, even without grazing.

**Figure 9.3 The possible effects of environmental change on stands of M10**



Heavy grazing can damage substratum and vegetation (affecting the least fertile sites most), causing a loss of particular species per unit area (although it is unknown to what extent this may result in significant species loss from the stand). M10 is often found on shallow well-flushed peat, often exacerbating impacts from heavy grazing and scouring during high flows.

Increased fertility can lead to invasion by taller, more vigorous plants (especially in the absence of grazing) leading to loss of typical M10 species. Evidence shows that this occurred in a few sites (for example, those supporting M10b). It is unclear whether damaging nutrient release can result from substratum mineralisation coupled with lowered water tables, partly because low-fertility soils often have a small starting nutrient capital, containing little organic material.

Figure 9.3 shows some of the possible floristic impacts of changes to the stand environment. The concept of 'vulnerability' is complex; depending on the starting conditions (including floristic composition), sensitivity of the stand and sensitivity of the site to change. Some stands may be regarded as *sensitive* to change but not necessarily *vulnerable*. For this reason, accurate assessment of vulnerability should require careful site-specific investigations.

### 9.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (for example, numbers of species lost, damage to substratum, degree of enrichment etc). There is limited information available that specifically relates to restoration of M10 stands, but the following observations can be made.

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M10 in the short to medium term.
- Scrub removal and re-instatement of vegetation management may help to restore M10 that has been left unmanaged, provided other conditions have not changed irreversibly.
- The potential for restoring high grade stands on dehydrated sites through the re-establishment of groundwater supply is unknown.
- Attempts to increase the wetness of M10 sites by blocking outflows could be detrimental to the vegetation if they result in stagnant, strongly reducing conditions.

### 9.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to M10 include the following:

- The data used are largely based on information held within the FenBASE database.
- Examples of the community from upland locations have not been examined.
- There are currently virtually no hydrometric data to better describe the temporal water table characteristics of M10 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M10 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at representative sites.
- Data on the spatial extent of M10 are lacking.
- Possible differences in environmental conditions influencing the three sub communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.