RELATIONSHIPS BETWEEN ECOTOPES, HYDROLOGICAL POSITION AND SUBSIDENCE ON CLARA BOG AND RAHEENMORE BOG (IRELAND).

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Abstract: An analysis was made of the hydrological position of five different ecotopes on the western half of Clara Bog and three on Raheenmore Bog, Co. Offaly, Ireland, as defined by Kelly and Schouten (2002). The ecotopes are defined in terms of microtopography and local hydrological conditions and correlate well with vegetation. The core quantity of hydrological position is the *potential acrotelm capacity*, defined by Van der Schaaf (2002) and Van der Schaaf and Streefkerk (2002). It is based on flow pattern, flow path length and local surface slope. A clear relationship was found between ecotopes and these three quantities. Effects of water divide shifts resulting from unequal subsidence resulting from internal drainage were also reflected in the results. The relationship between potential acrotelm capacity and the occurrence of the ecotopes was found to be generally well-defined, which indicates that potential acrotelm capacity is a useful quantity in assessing ecological potential in disturbed bogs.

INTRODUCTION

During the final stage of the Irish-Dutch Raised Bog Study (1989-2001), an effort was made to integrate aspects of vegetation, water quality and hydrology. The basic ecological concept used was the ecotope rather than the plant community,

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because the ecotope, although linked to plant community, is defined in terms of abiotic conditions. After a short description of the two bogs, the distinguished ecotopes are described, followed by hydrological concepts. After this, relationships are developed and discussed. Water quality aspects are not discussed in this paper. Instead, the reader is referred to Van der Schaaf and Streefkerk (2002).

CLARA AND RAHEENMORE BOG

Clara Bog and Raheenmore Bog are raised bogs in the Irish Midlands. Their geographic positions are shown in Figure 1. Clara Bog comprises almost 500 ha of bog, Raheenmore about 125 ha. Both have developed in basins formed during the Weichselian glacial period, when land ice covered most of the Irish Midlands.

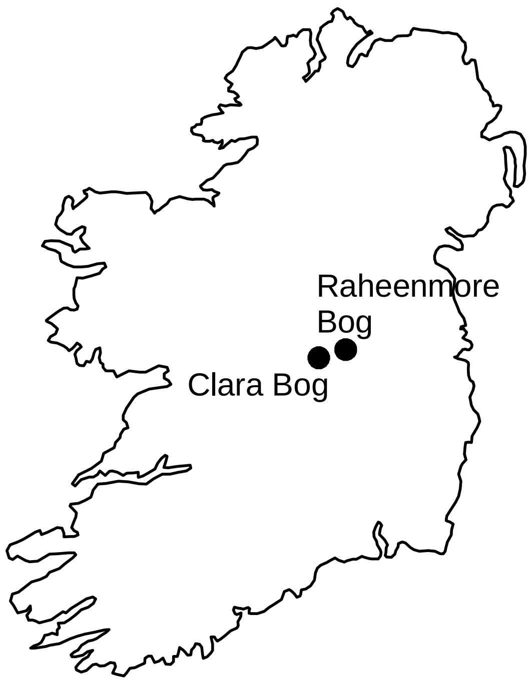

Figure 1. Positions of Clara and Raheenmore Bog

Clara Bog is a remnant of a larger bog, which has partly been cut over. Present-day Clara Bog is bisected by a road into two almost equally sized parts, Clara Bog East and Clara Bog West. The road was probably built around 1800. Clara Bog East was prepared for peat extraction around 1982-83 by the construction of a net of shallow drains with a spacing of approximately 20 m. The two bog halves

became a single nature reserve shortly after this event. Most drains were blocked provisionally around 1989 and finally in 1996. However, because of the drainage effects on the ecosystem of Clara East, this paper concentrates on Clara West.
The road and its associated drainage system have caused a subsidence of several m over most of Clara Bog. The subsidence has continued over the 20th century, in spite of the terrestrialisation of the drains on the bog. On Clara West it has resulted in a change of the originally radial diverging flow system to a converging flow system, which comprises almost 100 ha (Van der Schaaf, 1999, 2000). The main outlet near the bog lake Shanley's Lough (Figure 2) is about 250 m wide. Its position ensures permanently wet conditions in this part of the bog. The area is a so-called rheotrophic soak, an area of excessive wetness and lateral transport of water. Soaks are characterised by a vegetation type that indicates slightly more mesotrophic conditions than the usual bog vegetation. A more minerotrophic soak type, associated with the occurrence of bog lakes rather than converging flow, occurs on Clara East.

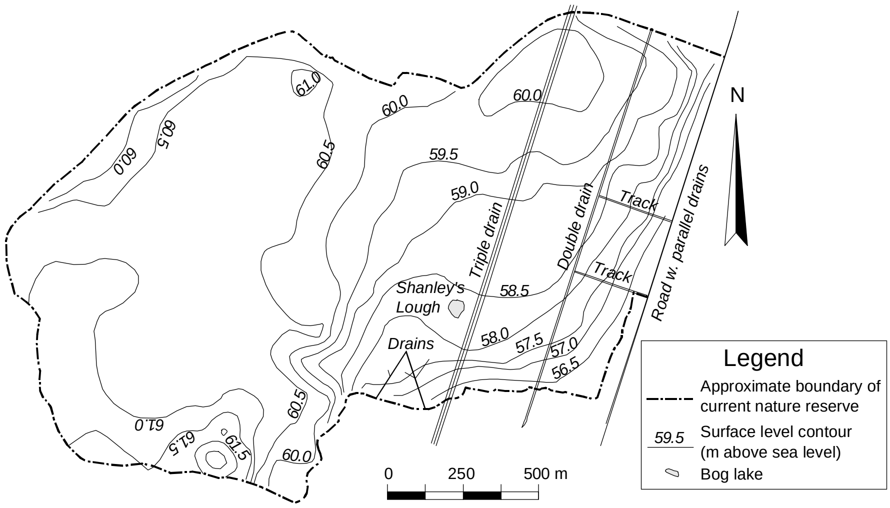

Figure 2. Map of Clara Bog West with surface level contours and system of drains (*Triple Drain* and *Double Drain*), associated with the bog road (on the right).

Raheenmore Bog has only been cut over in a narrow margin zone, locally up to 150 m wide, but often less than 50 m. In the eastern part a network of old terrestrialised drains occurs (Figure 3), which has been blocked around 1996. Raheenmore Bog is still dome shaped as Figure 3 shows, with the margin 3 to 7 m below the highest point.

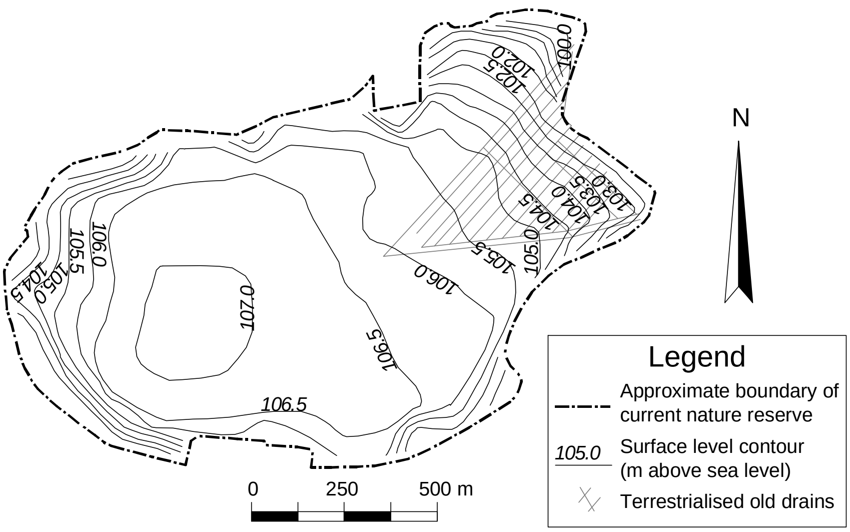

Figure 3. Map of Raheenmore Bog with surface level contours and the terrestrialised old drain system in the East.

ECOTOPES

The basic system is based on a concentric approach from centre to margin (Kelly and Schouten, 2002). It is shown in Figure 4.

Only the ecotopes of the high bog, except the face bank ecotope, are discussed in this paper. The lagg and cut-away ecotopes are only shown in Figure 4 to complete the picture. Soak ecotopes do not have a specific position in the concentric approach of Figure 4.

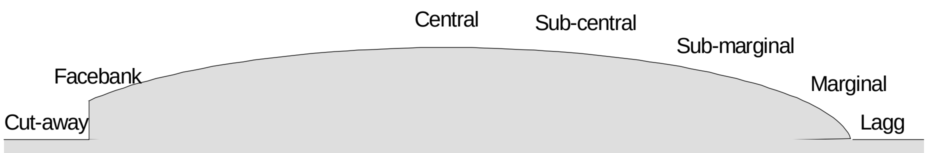

Figure 4. Approximate ecotope positions on a cross-section of an Irish raised bog.

As a result of the severe subsidence process over the last two centuries, the concentric pattern of ecotopes no longer exists on Clara Bog (Van der Schaaf, 1999, 2000; Connolly *et al.*, 2002). It is still fairly intact on Raheenmore Bog, which has subsided far less than Clara Bog (Kelly and Schouten, 2002). A description of the ecotopes mentioned in Figure 4 is given in Table 1.

Table 1. Description of ecotopes referred to in this paper (see also Figure 4).

Ecotopes	**Properties**	
Face bank	Abiotic	No hummocks or hollows. Mean phreatic level from several dm to about 1 m below the surface; seasonal fluctuation several dm, water table below the surface in all seasons; surface runoff may occur at peak rainfall. No functioning acrotelm.
	Biotic	No peat forming plant communities; vegetation usually dominated by *Calluna vulgaris*.
Marginal	Abiotic	No hummocks or hollows. Mean phreatic level usually 1-4 dm below the surface, seasonal fluctuation up to 3-4 dm. No inundation, except some by surface runoff at peak rainfall. Acrotelm absent or poorly developed (≤ 5 cm deep).
	Biotic	Few or no peat forming plant communities; vegetation dominated by *Calluna vulgaris* and *Scirpus caespitosus*.
Sub-marginal	Abiotic	Some differentiation between hummocks and hollows; hollows inundated up to 5% of the year. Mean phreatic level up to about 1 dm below the surface in the hollows; seasonal fluctuations up to 3-3.5 dm. Acrotelm absent or thin, nearly always ≤ 10 cm.
	Biotic	Hollows dominated by *Narthecium ossifragum* and *Sphagnum tenellum*; hummocks resemble those in ecotopes 4 and 5.
Sub-central	Abiotic	A microtopography of hummocks, hollows and lawns, no pools. Lawns are dominant. Inundation of lowest parts of lawns and hollows up to 70% of the year. Mean phreatic level around or a few cm below the average lawn surface; seasonal fluctuations generally about 2 dm. Acrotelm depth variable; locally well developed, up to about 4 dm deep, but also locally absent.
	Biotic	Lawns dominated by *Sphagnum magellanicum*
Central	Abiotic	A microtopography of hummocks, hollows and pools. Seasonal fluctuations of the phreatic level up to about 2 dm. Acrotelm moderately to well developed; depths up to 50 cm, rarely absent.
	Biotic	Pools and hollows dominated by *Sphagnum cuspidatum*.
Soak, rheotrophic	Abiotic	Generally wet to extremely wet conditions; in the wettest parts lawns, which may be partially inundated for more than 50% of the year; in some parts pools and hollows with large flat hummocks. Average phreatic level at or above the surface of the lawns; seasonal fluctuations up to about 20 cm.
	Biotic	*Sphagnum cuspidatum* and *Sphagnum recurvum* lawns with *Carex rostrata*; in drier places *Myrica gale* and *Betula pubescens* scrub woodland with *Sphagnum palustre* and *Polytrichum commune; Molinia caerulea* tussocks in some areas.

HYDROLOGIC CONCEPTS

The main hydrologic concept to be described here is *potential acrotelm capacity* (Van der Schaaf, 2002, Van der Schaaf and Streefkerk, 2002). It is based on the following considerations.

1. The acrotelm is the one and only aquifer in a raised bog.
2. Flow in the acrotelm obeys Darcy's law.
3. The hydraulic gradient in the acrotelm is approximately equal to the surface slope. Hence it remains approximately constant over the seasons.
4. As a consequence of points 2. and 3., the flow rate in the acrotelm can only be transmissivity-controlled.
5. Acrotelm transmissivity is controlled by the water table and the decrease of hydraulic conductivity with depth (Romanov, 1968; Ivanov, 1980)
6. Local acrotelm transmissivity is proportional to local flux, since the hydraulic gradient is approximately constant in time (point 3.).
7. Local flux is controlled by specific discharge (discharge per area [LT^{-1}]) and the upstream catchment area.
8. From points 6. and 7., it follows that in a healthy raised bog acrotelm transmissivity at any point in time is a function of time variant specific discharge, the upstream catchment area and local surface slope.

The process that keeps this mechanism going, is the feedback loop of the respective speeds of production and decay of plant remains, which are are fundamental in forming the acrotelm aquifer, but in turn depend on hydrological conditions determined by the same aquifer (Van der Schaaf, 2002). Potential acrotelm capacity τ_{ap} is defined as acrotelm transmissivity T_a [LT^{-2}] per specific discharge v_a [LT^{-1}] and hence has dimension [L]. In fact it is the coefficient of proportionality between v_a and T_a. It can be linked to surface slope I [1] and upstream flow path length L_u [L] by

$$\tau_{ap} = \frac{T_a}{v_a} = \frac{L_u}{fI} \qquad (1)$$

where f is a dimensionless flow path shape factor that assumes a value

1 for parallel flow,
2 for radially divergent flow and
<1 for convergent flow

(Van der Schaaf, 1999, 2002; Van der Schaaf and Streefkerk, 2002).

METHODS

The points of a 100*100 m grid, laid out on both bogs by the Office of Public Works and levelled in 1990 and 1991, were evaluated with the exception of the points situated in the area of Raheenmore Bog with old infilled drains, which was classified separately by Kelly and Schouten (2002). The evaluation included ecotope as identified by Kelly and Schouten, flow path length, surface slope I based on grid point levels, flow path length L_u and acrotelm depth, defined as the depth of the top layer with a degree of humification of 3 or less on Von Post's scale (Von Post, 1922).

RESULTS AND DISCUSSION

The results of Clara Bog are shown in Figure 5.

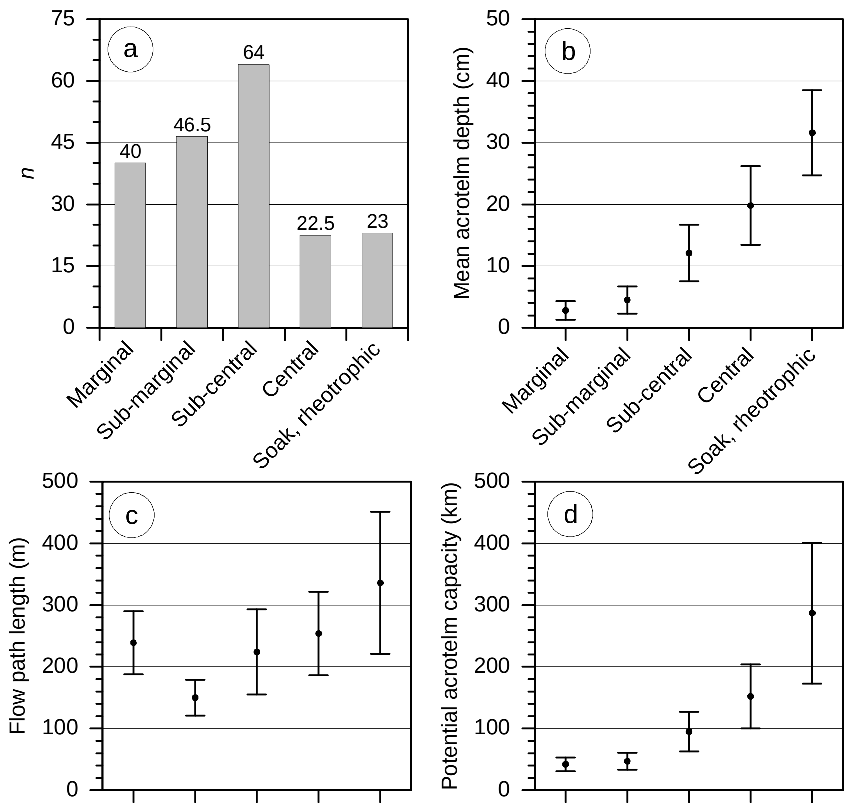

Figure 5. Clara Bog West. Number of grid points per ecotope (a). Means and 5% confidence intervals of acrotelm depth (b), flow path length (c) and potential acrotelm capacity (d) versus ecotope. Half a grid point means a transitional point between ecotopes.

The face bank ecotope was not included, because no grid point where *I* could be calculated from the elevation at four surrounding grid points, was available in the narrow zone of this ecotope. Figure 5a shows that marginal and sub-marginal ecotopes comprise about 44% of the area, suggesting a rather strong disturbance of the bog. The mean acrotelm depth in Figure 5b is in agreement with Table 1, with the smallest depths in the marginal ecotopes and the largest depths in the soak ecotope.

Based on Figure 4, an increase of the average upstream flow path length from central to marginal ecotope should be expected. However, Figure 5c shows an opposite picture, except for the marginal ecotope. This can be explained by the subsidence that has changed surface slopes and the position of water divides, thus turning the original radially diverging flow system into a converging one with some smaller diverging subsystems. At the new and still moving water divides on the bog, the surface slopes are often too steep to create sufficiently large values of potential acrotelm capacity τ_{ap} for a rapid acrotelm development. For such a development, a long upstream flow path, ensuring a lateral supply of water to compensate for rapid losses as a result of a relatively steep surface slope is required. This is in fact what Figure 5d tells. It shows a clear and significant relationship between τ_{ap} and ecotope. The rheotrophic soak system ecotope shows the highest values of τ_{ap} because of the converging flow system (f<1) and the long upstream flow path lengths L_u. Hence, the central ecotopes only subsist in bog parts away from the centre of the bog, with sufficiently large L_u, but not large enough to create conditions favourable for a soak ecotope.

The results for Raheenmore Bog are shown in Figure 6. The marginal ecotope zone area was too small to contain any grid points. Soaks do not occur on Raheenmore Bog. Hence only three ecotopes with a sufficient number of grid points for analysis are available for Raheenmore Bog. The acrotelm depth shown in Figure 6a is in agreement with Table 1, although the average depth tends to be a little smaller than on Clara Bog West. Again, the average flow path length is in disagreement with the supposed position on the bog. Most likely, this should be attributed to subsidence caused by the drains in the eastern part of the bog, which has caused a shift of the highest point of the bog in a westerly direction, thus creating an increase of the flow path length in the part to the east of the present-day apex position. Figure 6b suggests that the central ecotopes may have a slightly smaller τ_{ap}, although the difference is statistically insignificant. A likely explanation is that the bog in 1990-1992 when most of the field work was done, was still recovering from earlier damage (Van der Schaaf, 1999, 2002). During an acrotelm survey on Raheenmore Bog conducted in 2003, the existence of such a process could be confirmed (Van der Ploeg *et al.*, 2003).

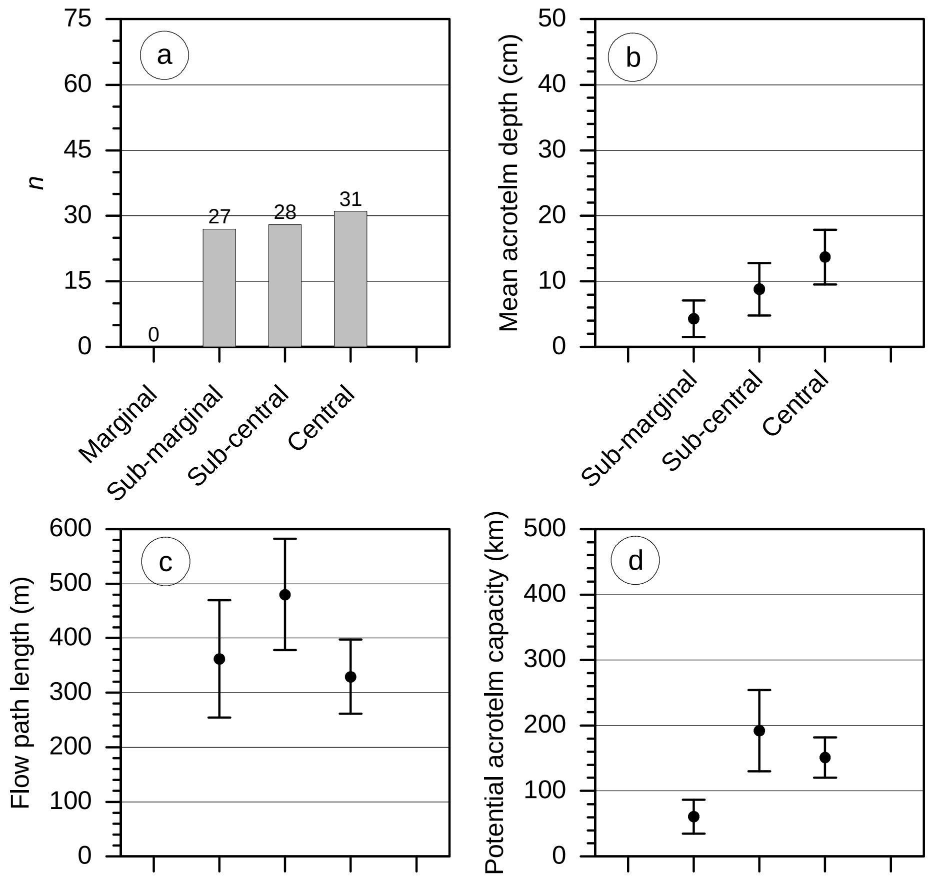

Figure 6. Raheenmore Bog. Number of grid points per ecotope (a). Means and 5% confidence intervals of acrotelm depth (b), flow path length (c) and potential acrotelm capacity (d) versus ecotope.

CONCLUSIONS

The results show that subsidence resulting from internal drainage on a raised bog causes a shift of water divides and as a result a relocation of ecotopes. Increased surface slopes have caused central ecotopes to move towards the margin, because longer flow paths are required to ensure sufficient wetness under these changed conditions. The value of *potential acrotelm capacity* correlated well with ecotopes as identified in the field. It can be entirely derived from a good elevation map (Eq. 1), which makes it a useful tool in assessing ecological potential.

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