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Department of Horticultural Science
University of Minnesota, St.Paul, MN

Raised Bog Restoration to Peat Producing Sphagnum Species: An Overview of European Approaches

Steve Roos

INTRODUCTION

The use of peatlands in Europe for human purposes has a history that dates back over a millennia. Before the advent of commercial exploitation, peat was used as a domestic fuel and the drained fields put into agricultural production. Urban and commercial expansion, beginning in the Middle Ages, created great demands for fuel. This demand, combined with shrinking woodlands, provided the incentive to develop methods of commercial bog exploitation (Borger 1990). The use of peat as a fuel continues up to the present, especially in peat rich, coal poor countries. Peat is also used extensively in horticulture as a soil conditioner, mulch and in growing media (Bather and Miller 1991). In addition, after the cessation of peat harvesting, bogs were almost always reclaimed for human use, most often for agriculture. Currently, commercial peat harvesting in Europe is concentrated on a specialized form of peatland, the raised bog. This extensive history of human influence has impacted the ecological processes to some degree in essentially every raised bog throughout Europe (Wheeler and Shaw 1995).

In recent times, there has been an increasing awareness of the value of natural systems. This awareness has extended to raised bogs not only for their value as a biological resource but also for their value as a renewable (albeit slowly) consumable resource. The importance of raised bogs in wildlife management, in the control of hydrological regimes and as global carbon sinks has also been identified (Bather and Miller 1991). For these reasons much recent research has been devoted to identifying suitable restoration techniques for raised bogs affected by peat extraction.

This paper provides an overview of the current research specifically aimed at the regeneration of raised bogs through revegetation with appropriate *Sphagnum* species. It explores issues dealing with the feasibility of restoration at a site specific level, in particular, the extent of damage that can be successfully ameliorated, the hydrology of the site in its current state and methods of restoring pre-harvest water levels and the presence of residual propagule material of sufficient quality to reestablish suitable plant populations. Recent work on encouraging the establishment of suitable plant populations will be investigated, including harvesting methods that leave propagule material on site, surface preparation techniques that promote regrowth and the influence of fertilizing on regrowth potential.

THE RAISED BOG ENVIROMENT

In attempting to define any wetland ecosystem it must first be made clear that wetlands most often represent a point along a continuum of natural developmental change. In the case of raised bogs, for example, the original ecosystem often began as open water progressing through swamp, fen, fen carr and finally to raised bog (Wheeler 1995). The various stages can be perceived as more or less stable in human terms, however, in geologic terms wetlands continue to evolve. This fact raises the problem of trying to define a specific ecosystem along a continuum that displays all the possible stages of transition. A second problem that consequently arises from the changing nature of wetlands is in attempting to define which stage along the continuum a given restoration project is intended to recreate. For the purposes of this paper the intended result is the recreation of a *Sphagnum* based, raised bog environment. Bearing in mind the above caution, a raised bog in its mature state is defined on three levels: a) its location and appearance in the landscape, b) its species composition, and c) the environmental factors that influence its development.

The very name "raised bog" indicates its paradoxical shape in the surrounding landscape. Raised bogs are wetlands with a surface raised above that of the surrounding drainage (Joosten 1995, Proctor 1995). This form is created by organic matter production, in the form of ombrogenous peat, that exceeds the rate of decay. Its nature as a wetland is maintained by the high water holding capacity of peat fibers. Raised bogs occupy flat sites in the landscape such as infilled glacial lake basins. They occur typically in the cool temperate zones of the Northern Hemisphere and to a much more limited extent in the Southern Hemisphere (Proctor 1995).

Very few species have the necessary properties to create a raised bog and then to continue to survive in this environment. Therefore, raised bogs tend to be species poor ecosystems dominated by *Sphagnums* including *S. papillosum, S. magellanicum, S. imbricatum* and others. The*Sphagnums* are referred to as the "key species" since their dominance is essential for bog formation (Joosten

1995). Under suitable conditions*Sphagnums* have the capacity to accumulate peat at a rate faster than decay occurs. As an ombrogenous peat layer develops, growing conditions become progressively harsher with a lowering of pH and available nutrient levels and a prevailing high water table (Proctor 1995). *Sphagnum* species are well suited to this environment and continue to dominate in a self perpetuating system (McQueen 1990).

As indicated by their natural locations, the primary environmental requirements of raised bogs are a cool climate and rainfall levels that routinely exceed evaporation. The excess rainfall combined with the raised surface of the bog create an environment where most of the available minerals are obtained from the rainwater, thus the term ombrotrophic, meaning that all nutrients come from precipitation. The result is a low pH, low nutrient environment dominated by *Sphagnums* (McQueen 1990).

PEAT EXTRACTION TECHNIQUES

Depending on the intended use of the mined peat, several differing methods of extraction can be used (Bather and Miller, 1991). The significance of the method employed lies in the extent to which the extraction removes the various layers of peat. A detailed later, the soil stratigraphy of a peat bog is divided roughly into two layers: the surface layer or 'top spit' (acrotelm) of approximately 30 cm., and the lower, black peat layer (catotelm) of varying depth. The extent of removal of these distinct layers is crucial to the prospects for restoration. The most common methods are:

- -- *Sod/Block Trench Cutting* -- this is the traditional method of peat extraction done by hand for centuries. Currently, hand labor is replaced by specialized machinery that cut sod blocks from trenches and stack the blocks in the field for drying. In this method the surface layer (top spit) is removed to a depth of approximately 30 cm. and stored in the cutting trenches. Due to its looser texture, the top spit does not cut into blocks well and is not considered economically valuable (Roderfeld, 1993).

- -- *Milled Peat Extraction* -- after the surface vegetation is stripped off, the bog surface is loosened to a depth of 15-50 mm., allowed to air dry and then collected most commonly with vacuum harvesters. Using this method, it is possible to harvest the top spit as a valuable raw material. It has been recognized that this loss can have a significant impact on the potential for restoration. For this reason, regulations have been imposed in many places to preserve the top spit material for eventual restoration efforts (Roderfeld, 1993).

- -- *Peat Extrusion* -- this method is used primarily in shallow peat deposits and small bogs. The peat is extracted by machine and extruded into "sausages" to dry. This method is used to produce peat for fuel.

- -- *Open Cast Black Peat Mining* -- this usually occurs after the looser, less decomposed "white" peat layer is removed. The black peat is mined with large equipment and methods somewhat similar to open cast mineral mining. The depth of excavation, in particular, the depth of black peat remaining at the bottom of the bog after extraction is completed, is critical to the restoration process (Roderfeld, 1993).

In Europe, surface milling is used on 65-80% of extraction sites with sod/block cutting accounting for 20-27% of extraction. Worldwide, milling is used for approximately 90% of peat extraction (Bather and Miller, 1991).

ASSESSMENT PROCESS

The prospects for successful restoration of any wetland depend on satisfying two main conditions:

1. -- re-establishing environmental conditions suitable to the desired ecosystem, and

2. -- providing a source of propagule material of the desired species.

Meeting these conditions depends greatly on the extent of the damage inflicted on a site. Depending on the damage, there are two possible strategies for restoration (Wheeler, 1995):

- --**Repair** -- which involves relatively simple interventions, usually restoring site hydrology. This method is well suited to minimally damaged sites exposed to lowered water tables or limited peat removal. Propagule material is already on site and surface topography is adequate or repairable with minimal effort.

- --**Rebuilding** -- which involves significant intervention in the restoration of site hydrology, topography and, possibly, the introduction of propagule material. This method is necessary on sites that have been badly damaged by peat extraction.

As mentioned earlier, a wetland represents a point along a continuum of development and is always evolving. While attempting to return a site to its immediate previous state is the most desirable approach, in considering the restoration of badly damaged sites, it has been argued that it must be realized and accepted that returning a site to a somewhat earlier developmental stage is all that can be practically and economically achieved (Wheeler, 1995). Assessing the feasibility of which approach to take depends on the degree of damage to the site's hydrology, topography and residual propagule material. These issues are site dependent and must be evaluated on that basis.

RESTORATION PROCESSES

***- Re-establishing Site Hydrology* --** Water is the single most important factor in the raised bog environment playing a critical role in its formation (Heathwaite et al, 1993). Drainage impacts the system by restricting the ability of a *Sphagnum* dominated vegetation type to re-establish. Drainage losses can occur by both internal processes, such as drainage canals and peat removal, and by external processes such as downward loss caused by penetrating the bog substrate or lateral losses caused by drainage of surrounding areas (Schouwenaars, 1992). Measures to deal with both of these water loss processes are needed in a successful water management plan for bog restoration. Based on evaluation and observation of experimental and implemented water management schemes, eight possible approaches to re-establishing site hydrology have been identified (Wheeler and Shaw, 1995):

- -- elevation of water level by ditch blocking,
- -- natural subsidence of peat to the position of the perched water mound,
- -- sculpting of the peat surface to the position of the perched water mound,
- -- elevation of the water level by containment within embankments,
- -- elevation of the water level by increasing water levels in the surrounding area,
- -- inundation using dams, -- reduction of the level of the peat

surface to form lagoons,

- -- provision of supplementary water.

Beyond the need to re-establish a water table that remains within 0.5-1 m of the bog surface throughout the year (Bragg, 1995), the source of the water is a crucial issue. As stated earlier, ombrogenous raised bogs are nutrient poor ecosystems that receive all their nutrients from precipitation (Proctor, 1995). Therefore, it is essential to monitor and control nutrient rich surface and groundwater inputs.

- Re-establishing Site Topography **--** The effects of site topography on the potential for restoration can be described on two levels -- surface topography and soil stratigraphy. On a macro scale, surface topography will have a pronounced effect on surface water runoff and the distance from the perched water mound to the bog surface (Roderfeld, 1993). If the surface gradient exceeds 5%, rewetting and establishment of *Sphagnum* growth will be nearly impossible (Heathwaite, 1993). Even slopes of 1% will allow significant erosion by surface water runoff. If surface leveling is impractical, the slope could be converted to a terraced series of polders or dammed ponds. This method provides some stabilization of ground water/bog surface distances. Terracing also minimizes the potential for erosion and aids in water infiltration (Roderfeld, 1993). On a micro scale, surface topography should be developed to mimic the "hummock and hollow" form of a natural raised bog. This micro relief provides varied micro environments that can be advantageous for the establishment of bog vegetation, especially *Sphagnums*. The hummock and hollow surface relief can be created easily with agricultural tillage equipment such as a moldboard plow (Heathwaite, et al, 1993).

Soil stratigraphy in a raised bog is broadly divided into two layers; the catotelm (lower black peat layer) and the acrotelm (upper white peat layer). These layers form under different conditions and perform different functions in the bog environment (Proctor, 1995; Bragg, 1995). The catotelm is permanently waterlogged and composed of highly decayed material. It functions as an almost impermeable seal for the bottom of the bog and as the primary water storage unit forming the perched water mound. The acrotelm is the "active layer" of the bog ecosystem where most of the biotic activity occurs as well as the active hydrologic fluctuations (Eggelsman, et al, 1993). The functions of the acrotelm include protecting the catotelm from evaporation, providing additional water storage and providing the location of biotic activity

(Roderfeld, 1993).

The functions of the catotelm and acrotelm play an essential role in the restoration process. Therefore, the extent of peat mining has a significant impact on the potential for restoration success. It has been determined that the hydrologic function of the black peat catotelm is met by a minimum thickness of not less than 50 cm. The requirements of the white peat acrotelm are met when the top spit is protected from decomposition by maintaining its moisture content and by returning it to the bog surface to a depth of at least 30 cm. (Roderfeld, 1993).

- Re-establishing Appropriate Bog Vegetation -- The restoration of an ombrogenous raised bog cannot be considered successful unless a*Sphagnum* based plant community is re-established on the site. Several issues significant to this goal, i.e., site hydrology and topography, have already been discussed. It is clear that adequate water levels must be achieved and maintained. The importance of the acrotelm and catotelm in regard to water management has been demonstrated as have the benefits of surface topography manipulation to create micro environments appropriate for Sphagnum establishment. The remainder of this section is devoted to suitable propagule sources and the benefits, if any, of fertilization.

The degree of damage imposed on a bog has a significant impact on the prospects for restoration. Numerous examples exist of spontaneous revegetation on sites suffering minimal extraction or disturbance (Wheeler and Shaw, 1995). An immediate source of propagule material, both vegetative and in the seed/spore bank, is an obvious advantage. Under otherwise favorable conditions, the rate of revegetation can be impressive, with pioneer vegetation cover, including *Sphagnum* species, quickly achieved (Wheeler, 1995; Joosten, 1995).

However, the response of spontaneous regeneration on seriously cut-over and damaged sites is far less impressive. Evidence indicates little natural re-establishment of bog key species on large scale, commercially cut-over bogs (Joosten, 1995). This slow natural response indicates that intervention is necessary to increase the rate of revegetation. Research has begun on several possible approaches. The potential of the diaspore bank and diaspore rain for revegetation has been studied. Not many species seem well adapted to long distance dispersal by the wind, however, it has been shown that many bog species are adapted to long distance dispersal by water. Vegetative parts of *Sphagnum* species appear to be dispersed by both wind and water. Research on the diaspore bank and its persistence show promise for restoration potential. Studies of top spit material indicate that most bog species are present in the diaspore bank with many showing relatively long term persistence. These studies, in particular, verify the value of preserving top spit material for reintroduction of plant material to a mined site; however, constantly moist conditions appear to be an important factor in persistence (Poschlod, 1995).

The best prospects for re-establishing appropriate bog species involve the introduction of propagule material through human intervention. Studies indicate initial success at establishing Sphagnum species as whole plants if other factors, especially hydrology, are adequate. Additional studies have shown success at establishing *Sphagnum* species from fragments spread by 'Hydroseeding'. This method would also be a very practical way of inoculating large areas (Money, 1995).

Low level of nutrient inputs and recycling in a natural raised bog system indicate that large amounts of chemical inputs are not warranted. However, studies indicate that *Sphagnum* growth can be encouraged by modest additions of phosphorus (Money, 1995). Caution must be exercised, though, in any application and other inputs of phosphorus, i.e., surface water inputs, should be monitored carefully to prevent over fertilization and stimulation of unwanted species.

SUMMARY

Despite the apparent successful regeneration on historic and small scale current sites, the extent of damage done with modern methods of peat extraction create a far more difficult restoration task. Recent research has identified mining practices that offer improved prospects for successful re-establishment of site hydrology and topography. Revegetation can be encouraged by careful handling and replacement of the top spit combined with introduced propagule material when necessary. However, due to the slow redevelopment of raised bog systems, evaluation of success is difficult. In light of the human tendency to desire quick results, Joosten suggests that bog restoration should perhaps be called a "success" when a permanent establishment of key bog species has been realized (Heathwaite, et al., 1993).

In spite of this optimistic evaluation of success, it is apparent that true restoration of a raised bog ecosystem is a long term process. Joosten, himself, makes this point clear, "Long term studies in bog regeneration indicate that restoration of bogs as self-regulating landscapes after severe anthropogenic damage is impossible within human time perspective, because the necessary massive re-establishment of bog key-species and renewed accumulation of peat require centuries" (Joosten, 1995).

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