CHARACTERISTICS OF THE LOW-ELEVATION *SPHAGNUM*-DOMINATED PEATLANDS OF WESTERN WASHINGTON: A COMMUNITY PROFILE

PART1: PHYSICAL, CHEMICAL AND VEGETATION CHARACTERISTICS

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PREFACE

This paper compiles information about *Sphagnum*-dominated peatlands of western Washington. It concentrates primarily on low-elevation peatlands, defined as those being below about 600 meters (2,000 feet) mean sea level (msl). The format of this paper follows that of the U.S. Fish and Wildlife Service for community profiles of wetland ecosystems. Even though the format is that of a community profile, the amount of research information available for western Washington peatlands is considerably less than for other community profiles in this format, specifically the peatlands of northern Minnesota (Glaser 1987) and tundra ponds of the arctic coastal plain (Hobbie 1984).

Other than the early work of George Rigg and others in the 1940s and 50s, little data have been generated about western Washington peatlands. Except for work on vegetation communities by Kunze (1994), most of the information that does exist has been produced in connection with development proposals rather than by university or government researchers, making access to the information extremely difficult for most wetland scientists. This Community Profile synthesizes this disparate and largely unpublished information and makes it more widely available to wetland scientists, researchers and regulators. This effort was motivated by a concern that *Sphagnum*-dominated peatlands are in peril in much of western Washington. The lack of information has made effective conservation efforts difficult to pursue. It is our hope, therefore, that the information presented in this report will be of value in fashioning better protection measures, formulating much-needed research activity, and in enhancing an understanding and appreciation of these unique wetlands.

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CHAPTER 1: INTRODUCTION

Sphagnum-dominated peatlands are relatively scarce in the western Washington. A casual perusal of the King County Sensitive Areas folio leads to the realization that wetlands in which at least some portion of the plant community *Sphagnum*-dominated comprise only about three per cent of the total inventoried wetlands (extracted from King County, 1980). These peatlands, by definition, have *Sphagnum* mosses forming the predominant portion of the ground layer. The *Sphagnum* typically forms a hummocky topography of small mounds, although flat expanses also occur. Ericaceous shrubs that are very uncommon in western Washington, apart from *Sphagnum* substrates, are frequently found growing in these peatlands. In particular, *Ledum groenlandicum* (Labrador tea), *Kalmia microphylla* (bog laurel) and *Vaccinium oxycoccous* (bog cranberry) are especially common on the *Sphagnum* mat [1] (see Figure 1.1, 1.2 and cover photograph). In addition to supporting a unique community of ericaceous shrubs and other plants, *Sphagnum*-dominated peatlands are acidic and typically have tea-stained waters rich in tannins and organic acids.

The purpose of this document is to present information that currently exists about the *Sphagnum*-dominated peatlands[2] of lowland western Washington and to place that information in the context of our understanding, primarily from literature sources, of other *Sphagnum*-dominated peatlands elsewhere in the northern hemisphere. Even though Washington's peatlands are poorly studied, sharing the information that is available can help wetland scientists establish a common base of knowledge about this infrequent wetland type. It is also hoped that this document will make obvious the need for better data to understand and manage these unique wetlands.

FIGURE 1.1 *Kalmia microphylla* in bloom with *Ledum* foliage in background.

1.1 Paper Organization

This report is Phase one of a two-part Community Profile of western Washington peatlands. This first phase consists of five Chapters covering the basic physical, chemical and vegetation information available for this area. Additional draft chapters presenting initial management and research recommendations are provided in Appendix A. References are at the end of each Chapter, and a bibliography of peatland literature is in Appendix D.

Chapter One describes some of the basic summarizes the gradients operating in peatlands, and presents the basis for identification of peatlands included in the report.

[1] In a survey of 30 peatlands in King County, *Ledum groenlandicum*, occurred in all 30, *Kalmia microphylla* occurred in 67%, and *Vaccinium oxycoccous* occurred in 57% (L. Kulzer, unpublished field notes).

Chapter Two discusses the physiographic provinces of western Washington and the physical properties of *Sphagnum*-dominated peatlands, both in a general sense, and specifically those identified in Appendix B of this report.

Chapter Three presents water chemistry information available for four *Sphagnum*-dominated peatlands. Chemical characteristics of other water sources that may influence *Sphagnum*-dominated peatlands, such as precipitation, groundwater, and chemistry data for other surface waters, are also presented.

The fourth Chapter discusses the biology, taxonomy, and ecology of *Sphagnum* species found in western Washington. Many of the underlying factors that affect the distribution of the *Sphagnum* species of western Washington peatlands are summarized.

Chapter Five covers the vegetation of *Sphagnum*-dominated peatlands. Information on the vegetation of *Sphagnum*-dominated peatlands in western Washington relies primarily by Kunze (1994).

FIGURE 1.2 *Ledum groenlandicum* in bloom.

Appendix A contains drafts of two important chapters that will be finalized when all the information in Phase 2 has been assembled. Those drafts are on preliminary management guidelines and research needs. Appendix B presents information about the location and characteristics of *Sphagnum*-dominated peatlands of western Washington lowlands by county. Appendix C contains expanded physical, water chemistry and vegetation information summarized in Chapters 2 through 5. A bibliography for *Sphagnum*-dominated peatland literature, arranged by author, is presented in Appendix D. Appendix E is a draft key to the *Sphagnum* species found in western Washington.

[2] *Sphagnum*-dominated peatlands are those peat-accumulating systems in which *Sphagnum* mosses dominate the lowest layer of vegetation. Acid peatland is also used interchangeably with the term *Sphagnum*-dominated peatland.

1.2 Conditions Favoring Formation of *Sphagnum*-dominated Peatlands

Peatlands occur when the rate of production of organic material exceeds the rate of decomposition (Moore and Bellamy 1974), causing partially decomposed organic matter to accumulate[3]. It is not so much that the production of organic matter is unusually high in peatlands, but that the rate of decomposition is unusually low (Craft and Richardson 1993; Reader and Stewart; 1972). This slowed rate of decomposition is typically due to a combination of water-logging, acidity, and anoxic conditions (Clymo 1984; Malmer 1986; Glasser 1987; Crum 1992). Gignac and Vitt, 1994,.state that the two most important factors maintaining slowed decomposition rates are cold temperatures and high water levels. Most investigators classify wetlands as peatlands when the amount of organic material accumulates deeper than 30 to 40 cm (12 to 16 inches) (Kivinen and Pakarinen 1981; in Glaser 1987; Gorham et al. 1984; USDA 1975; Zoltai 1987; Zoltai et al. 1988). The National Wetlands Working Group of Canada uses 40 cm (16 inches) as the division between peatlands and non-peat-forming wetlands (National Wetlands Working Group 1988).

Peatlands are, in large measure, a product of northern climates. The United States ranks third in world peatland resources (Vitt 1994), with Canada and the Commonwealth of Independent States, formerly the USSR, far outranking it in terms of peatland area[4]. The vast majority of U.S. peatlands are in Alaska. Washington has relatively few peat resources, ranking 21st of all 50 states in the extent of peat soils (Malterer 1996).

A typical set of allogenic, or external factors, are associated with acid, or *Sphagnum*-dominated peatlands. First, in the water balance, precipitation exceeds evapotransportation. This can occur either because of very high rainfall and mild temperatures, as in maritime climates, or in situations of more moderate rainfall but lower average annual temperatures, as in more northerly continental climates. Moisture deficit, defined as precipitation minus potential evapotransporation, is another way to describe the water balance, and acid peatlands are found where the moisture deficit is positive. Secondly, the substrate tends to be infertile. Glaciated regions and granitic substrates are common in areas with *Sphagnum*-dominated peatlands. These parent materials tend to be low in available nutrients and minerals. Thirdly, poor drainage and stagnant water are also requisites for the development of acid peatlands. Poor or stagnant drainage occurs in plateaus, drainage divides or "saddles," river flood plains, and coastal strand areas. Acid peatlands can also develop in stagnant zones created by surface water flow obstructions within more extensive peatland complexes (Glasser 1994; Halsey, Vitt and Zoltai 1997).

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[3] Accumulated organic matter is classified by soil scientists as either peat or muck, depending on the degree of decomposition.

[4] Canada has about 170 million hectares of peatlands, the Commonwealth of Independent States (formerly USSR) about 150 million hectares, and the U.S. about 36 million hectares (Vitt, 1994).

In western Washington, *Sphagnum*-dominated peatlands are concentrated in the Puget Sound lowlands, particularly Snohomish, King and southern Mason Counties.[5] These areas have high annual rainfall, mild winter temperatures, and cool summer temperatures.

1.3 Peatland Classification: the Bog to Fen Gradient

Terminology in peatland literature is particularly challenging. The development of peatland naming conventions or classifications will be summarized in this section, followed by definitions of the more common terms that describe peatland features in Section 1.4. A glossary of terms is found at the end of the paper, following Chapter Five.

Investigators from different countries have developed distinct sets of terminology throughout the 20th century to describe the peatlands of their respective areas. Often, a naming convention developed in one area did not adequately differentiate the peatland characteristics in other areas. New names or redefinition of old names occurred to fit different physical features or different ideas about the importance of allogenic or autogenic peatland influences. In general, though, the terms bog and fen are the most commonly used to describe different types of peatlands. Both bogs and fens are peat accumulating systems. Bogs and fens can be thought of as describing a continuum of peatlands, rather than two distinct, separate groupings. In this continuum, the variables of vegetation (*Sphagnum* vs. sedge dominated), chemistry (acidic vs. circumneutral) and source of water (rainfall vs. groundwater) differ along gradients. These three variables have been the ones most often used by scientists to differentiate peatlands along the bog-to-fen continuum. Although the two extremes of the bog-to-fen continuum would bear the same name (bog or fen) using any of the variables, peatlands in between the two extremes would be named differently depending on whether vegetation, chemistry, or source of water is used to distinguish them. Even recently, significant discussion pertaining to naming conventions appears in scientific journals (Bridgham 1996; Wheeler and Proctor 2000).

One of the first peatland classification systems was developed by Weber (1909, reviewed in Zoltai 1988). It was based on the physiogomy or cross-sectional profile of the peatland. Weber differentiated between hochmoore and niedermoore, with an intermediate ubergangmoore. Generally, these German terms correspond to the English terms bog (hochmoore) and fen (niedermoore). In the first half of the 20th century, the terms bog and fen were used relatively loosely to define peatlands with differing characteristics along several gradients that included acidity as well as vegetation.

In the 1950s, the terms bog and fen were further differentiated by the Scandinavian scientists DuRietz and Sjors. Both investigators distinguished between bogs and fens based on floristic makeup; however, Sjors also investigated the pH characteristics of the categories he established based on floristics. DuRietz (1949) established four categories: bog, poor fen, moderately rich fen and extremely rich fen based on the

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[5] Data are for peatlands identified as *Sphagnum*-dominated at the surface in Rigg, 1958.

"poorness" or "richness" of the vegetation. Sjors (1950) established six categories along the bog-to-fen gradient: moss (bog), extreme poor fen, transitional poor fen, intermediate fen, transitional rich fen and extreme rich fen. pH was investigated for each of these categories, with considerable overlap between most of the categories. During the same time period, Kulczynski (1949), a German investigator, distinguished between bogs and fens based on whether or not the peatland was influenced by flowing groundwater, and whether the groundwater was from the immediate catchment only or also from outside the immediate catchment.

In the latter half of the century, peatland naming conventions continued to be refined and redefined. Malmer, a Swedish investigator, gravitated to the terms bog, poor fen and rich fen (1965, 1968, and 1986). Similar to Sjors, Malmer associated certain pH thresholds with these terms. Moore and Bellamy applied the terms ombrotrophic, mesotrophic and rheotrophic to differentiate bogs, poor fens and rich fens. These terms were based on water mobility, with ombrotrophic peatlands receiving precipitation only, and rheotrophic peatlands receiving ground and surface water flows. Mesotrophic peatlands were intermediate between the ombrotrophic and rheotrophic peatlands, but not clearly differentiated in this scheme.

More recently, investigators employing quantitative methods relating physical, chemical, and vegetation variables using detrended correspondence analysis (DCA) or detrended canonical correspondence analysis (DCCA) have found support for four categories of peatlands (Kivinen and Pakarinen 1981; Gignac and Vitt 1990; Vitt and Chee 1990; Vitt 1994; and Halsey et al. 1997). These categories include bogs, poor fens, moderately rich fens and extreme rich fens. Vitt (1994) also associated pH ranges with these categories. Sometimes bogs and poor fen categories were lumped into a single *Sphagnum*-dominated peatland category (Gignac and Vitt 1990), and several other investigators have concluded there is less distinction between the bog and poor fen categories than between the intermediate and rich fen categories (Malmer 1986; Damman 1995 in Wheeler and Proctor 2000).

Although the technical literature reflects complex distinctions between types of bog and fen peatlands, Mitsch and Gosselink (1986), in their textbook summary of peatlands, defined the two extreme ends of the bog-to-fen continuum. The two categories (bog and fen) they defined combined vegetation indicators with surface hydrological characteristics in a way that mixed categories of previous investigators. The 2000 edition ot Mitsch and Grosselink updates their previous exposition of peatlands relying heavily on the recent work of Bridgham (1996) and Glasser (1997), and gives a more complete summary of classification historic schemes. Crum (1992), also in a textbook-like compilation, offered the opinion that the best classifications are based on water source and water movement. Table 1 summarizes some of the main historical distinctions made in classification along the bog-to-fen gradient.

TABLE 1: Historical distinctions between bog and fen peatlands.

Author	**← More Acidic**	**Less Acidic →**

Mitch & Grosselink (2000)	Bog: *Sphagnum*-dominated		Fen: sedge and grass-dominated			
Vitt (1994), Halsey, et al. (1997) Canada	Bog: *Sphagnum* dominated pH<4	Poor fen: *Sphagnum* dominated pH= 4-5.5			Rich fen: pH > 5.5 Moderate rich fen pH 5.5-7	Extreme rich fen pH 7-8.5
Gignac & Vitt (1990)	*Sphagnum* -dominated (bogs and poor fens)				Rich fens	
Moore & Bellamy (1974)[6] Euorpean	Ombrotrophic mires	Mesotrophic mires			Rheotrophic mires	
Malmer (1965, 68, 1986) Sweden	Bog pH<4.2 (summer)	Poor fen			Rich fen pH>5.5 (summer)	
Kulczynski (1949)	Ombrophilous mires- not influenced by flowing groundwater	Transition mires- influenced by groundwater flowing from immediate catchment only			Rheophilous mires- influenced by groundwater flowing from outside immediate catchment	
Sjors (1950)[7] Fennoscandia First to link floristic indicators to water pH.	Moss pH 3.7-4.6	Extreme poor fen pH 3.8-5.2 (includes indetermin-able poor fen)	Transi-tional poor fen pH 4.5 - 6.5	Intermediate fen pH 4.5-6.5	Transitional rich fen pH 5.7-7.8	Extreme rich fen pH 7.1-8.5
DuRietz (1949-50) Sweden (in Malmer 1986)	Bog- *Sphagnum* dominates bottom vegetation layer	Poor fen *Sphagnum* dominates bottom vegetation layer			Rich fen[8] Moderately rich fen "brown moss" dominates	Extremely rich fen
Weber (1909)[9] German	Hochmoore	Ubergangsmoore			Niedermoore	

Many investigators have noted that detailed hydrological measurements and an analysis of isolating mechanisms are often required to determine if the surface peat layers are strictly rainwater-fed, or if they are influenced by mineral-enriched ground or surface waters. This makes a naming convention based on water source difficult to apply in the field (Siegel and Glaser 1987; McNamara et al. 1992; Podniesinski and Leopold 1998). Therefore, application of these terms to specific peatlands is often imprecise and

[6] Classification based on water mobility in the mire
[7] Categories based on floristic makeup. pH was recorded once categories established.
[8] NOTE: terms poor and rich refer to the vegetation, not nutrients or cations

subject to differences of opinion. The difficulty in measuring hydrological influences has, in part, lead to the widespread use of chemical, vegetation and floristic indicators.

Recently, Bridgham et al. (1996) called for a new paradigm in the naming of peatlands (as well as the use of terms describing peatland systems). He called for the terms bog and fen to be used broadly, based on chemistry and plant species, and "…without accompanying assumptions regarding hydrology, topography, ontogeny, nutrient availability or the presence or absence of non-dominant indicator plant species." Gignac and Vitt (1990), Gorham and Janssens (1992), and Malmer et al. (1992) also observed that *Sphagnum* moss-dominated bogs and poor fens contrast markedly with brown moss-dominated moderate and rich fens, suggesting the distinction between bogs and poor fens is, in large part, artificial. Gorham and Janssens, looking at continental North American peatlands, argued for a distinction between bogs and fens based on *Sphagnum* versus brown moss domination of the ground layer.

Even more recently, Wheeler and Proctor (2000) have concluded that the mineral-soil-water distinction between peatlands is not sharp. Furthermore, Wheeler and Proctor's analysis of European peatlands shows that distinctions between rain and mineral soil-water cannot be related to consistent differences in vegetation or water chemistry. They recommend, with Damman, (1995) that classifications based on mineral soil water be abandoned, and that the term 'bog' should encompass weakly "minerotrophic" as well as "ombrotrophic" peatlands. Although Vitt (1990) and Bridgham et al. (1996) would share this general conclusion of broadening the application of the term 'bog', they would base this broadening on dominance by *Sphagnum* and the chemistry of ecosystems rather than the inexact terms ombrotrophic and minerotrophic.

Confusion in terminology has occurred because the distinctions between bog and fen have been made using several different criteria (floristic, chemical and hydrological) and because of variations in regional common usage. This confusion is evident in the state of Washington. Many early studies of peatlands in the region used the term, *Sphagnum* bog, to describe a peatland dominated by *Sphagnum* moss, both in terms of surface cover and in terms of peat composition (Fitzgerald 1966; Rigg 1916, 1919, 1925, 1940; Rigg and Richardson 1938). While rainwater-fed bogs are almost always characterized by a ground layer of *Sphagnum* mosses, these mosses also commonly dominate the ground layer of poor fens in many classification schemes (Vitt 1994). The term bog was also used historically, not in the strictly defined sense of an ombrogenous peatland, but as a term equivalent to *Sphagnum*-dominated peatland (Rigg 1958).

To avoid the confusion and the accompanying implications as to external environmental characteristics, the terms "*Sphagnum*-dominated peatland" and "acid peatland" are used in this report rather than the terms bog or fen. The terms *Sphagnum*-dominated peatlands and acid peatlands are used interchangably to mean those peatlands in which *Sphagnum* mosses form the ground layer of the wetland vegetation community, the pH is 5 or lower, and which lie above organic, rather than mineral soils. No organic soil

[9] Categories based on ontogeny (stages of development from groundwater influenced to raised peat domes)

depth is implied with the use of these terms for this report since information on the depth of subsurface soils is not available for most of the peatlands inventoried. Using the categories of Vitt (1994) and Halsey at al. (1997), *Sphagnum*-dominated peatlands include both bog and poor fen categories.

1.4 Terminology Related to Peatlands

Just as the terms for distinguishing between peatlands have had a long and varied history of development and have not yet achieved a widely accepted standard usage, so also has peatland terminology grown from many roots and has not come to an agreed upon standard for all terms. The uses given here follow those suggested by Bridgham et al. (1996), Wheeler and Proctor (2000), and Vitt (1994). If the recommendations of these investigators conflict, differences are explained in the text.

Ombrotrophic-minerotrophic and ombrogenous-geogenous

Perhaps the most-used term in referring to acid peatlands is **ombrotrophic**. The suffix "trophic" is commonly used in limnology as well as in reference to peatlands (e.g. eutrophic, oligotrophic). Indeed, limnologists commonly refer to the "trophic" state of lakes. In limnology, "trophic" refers to the nutrient status of the water body – whether it is nutrient enriched or nutrient poor. Typically phosphorus is used to define the trophic state of lakes (Hutchinson 1957). The typical trophic categories in lakes are oligotrophic, mesotrophic, eutrophic and dystrophic, from least to most nutrient enriched. In relation to peatlands, ombrotrophic is often used to refer to the **source** of water or nutrients in the peatland. The root "ombros" comes from the Greek, meaning a rainstorm sent by Zeus, and ombrotrophic is often used for those peatlands deriving water only from rainfall, or along the bog to fen gradient, bogs. However, there are problems with this usage. Bridgham et al. (1996) and Wheeler and Proctor (2000) suggest that the suffix "trophic" be reserved for references to the **nutrient status** of peatlands, rather than the source of water or the base richness. Vitt (1994) suggests that the suffix "trophic" should refer to the nutrient status of vegetation in peatlands. Strictly speaking, the terms ombrotrophic and minerotrophic would have little literal meaning, since "ombro" (rainstorm) and "minero" describe the source rather than the amount or concentration of the nutrients. However, ombrotrophic is often used in reference to peatlands to mean ultra-oligotrophic.

Both Bridgham and Vitt support use of the terms **ombrogenous** and **geogenous** when referring to the source of water or hydrology in peatlands; the suffix "genous" coming from the Latin root *gener*, *genus* meaning birth or origin. Thus ombrogenous peatlands receive water only from rainstorms, and **geogenous** peatlands also receive water that has been in contact with the earth, either surface or ground waters. Unfortunately, Wheeler and Proctor (2000) still used the terms ombrotrophic and minerotrophic in their essay on peatland terminology. Agreement on standard usage for these terms is still an unachieved goal.

The terms **topogenous**, **limnogenous** and **soligenous** are also used to describe the origin of peatlands. Topogenous peatlands refer to those that develop in topographic depressions or kettleholes left by melted ice. **Limnogenous** peatlands are those that are affected by inundation or permanent influence of water from rivers or lakes. They often develop along the margins of lakes or rivers or in river flood plains. **Soligenous** peatlands are affected by groundwater or springs water issuing along slopes. Aapamires is the general term for peatlands developed on slopes. Aapamires are usually characterized by slow down-slope movement, and develop characteristic ridges of peat perpendicular to the direction of flow (strings) alternating with watertracks that are not dominated by peat (flarks).

Bridgham et al. (1996) suggest use of the words "strongly acid, weakly acid and circumneutral" to describe the pH of peatlands. Further, they suggest that the terms rich and poor are too inexact to describe the alkalinity of peatlands. Wheeler and Proctor suggest that the terms oligotrophic, mesotrophic and eutrophic not be applied to base richness of peatland waters, but be limited to major nutrients, mainly nitrogen and phosphorus.

1.5 Gradients in Peatlands

The major gradients in peatlands have already been mentioned superficially in the previous section on peatland classification. These include a) vegetation, b) chemical, especially acidity/alkalinity gradients, and c) gradients in the source of water. A fourth important gradient relates to movement of water in peatlands.

Vegetation gradients

Peatland investigators have been examining the gradients in vegetation in peatlands, both at the ground surface and in the herb, shrub and tree layers, for over a century. In most regions with varied peatland types, vegetation gradients have offered clues to the processes shaping peatlands. And many investigators have also commented on the fact that *Sphagnum* can actively alter environmental conditions, acting as an autogenic factor in forming peatland characteristics (van Breemen 1995). At the ground layer the dominant gradient is from *Sphagnum* moss at one extreme, to brown mosses to sedges and grasses at the other extreme. Indeed, the *Sphagnum* mosses are not all of a kind, but in themselves show gradation based of different environmental variables (Vitt et al. 1975; Horton et al. 1979; Clymo and Hayward 1982; Andrus 1986; Vitt et al. 1989; Gignac and Vitt 1990; Bates and Farmer 1992; Vitt et al., 1995). Shrubs found in peatlands also show gradations, similar to those of the ground vegetation layer. These range from the dominant ericaceous shrubs of the most acidic *Sphagnum*-dominated peatlands to plants considered base indicators in calcium-rich fens. In recent decades, vegetation studies have made use of sophisticated analytical methods to discern grouping and gradients which would be difficult to identify otherwise (Vitt and Slack 1974; Vitt et al. 1989; Nicholson and Vitt 1989; Gignac and Vitt 1990;

Halsey et al. 1997). Even so, recognition of vegetational gradients in peatlands dates back to before the turn of the century.

Acidity/alkalinity gradients

It is widely acknowledged that *Sphagnum* mosses can mediate the acidification of the waters in which they grow (Crum 1992; Clymo 1963). Thus, a gradient from acidic to circumneutral (pH of around 7) to basic (in calcium-rich fens) is seen. Alkalinity concentrations generally follow the pH gradient, with very low alkalinities in acidic waters and very high alkalinities in calcium-rich waters. Although pH-alkalinity gradients exist, it has also been noted that there seems to be a bimodal (rather than continuous) distribution in pH and alkalinity of acidic peatlands (Gorham et al. 1984; Vitt, 1994). Acidic peatlands with pH ranges below 5 form one mode, and rich fens with pH above 5.6 form the other. There seems to be fewer peatlands with pH in the range of 5.1 to 5.6 (Vitt 1994). This observation is related to the carbonate-bicarbonate equilibrium discussed in Chapter 3.

Source of water

The source of water has long been recognized as contributing to gradients in peatlands, and has been used to differentiate peatlands in some classification schemes (Moore and Bellamy, 1974). At one extreme are peatlands influenced only by rainwater, and at the other extreme are those peatlands influenced by mineral-rich groundwater. Surface water and mineral poor groundwater can be seen as having intermediate influences on peatlands.

Movement of water

Whether water is stagnant or moving has a profound effect on peat accumulation. Moving water has both physical effects as well as chemical ones. Moving water is able to supply many more nutrients, even if concentrations at any one time are fairly low. On an annual basis, nutrients and cations supplied by moving water can contribute substantially to the overall nutrient budget of a system. Movement of water was seen by Kulczynski (1949) as a major factor in differentiating bogs from fens, which he termed ombrophilous and rheophilous mires.

Other gradients

In addition to the four major gradients described above, other peatland gradients also have been acknowledged. These include micro-topographic gradients from the edge to the center and also from hummock to hollow in *Sphagnum*-dominated peatlands. Nutrient scarcity or abundance, sunlight to shade, and seasonal gradients can also vary in peatlands and affect the expression of vegetation and chemistry characteristics.

Micro-topographic gradients

Micro-topographic gradients in hummock-forming peatlands are important, and provide a variety of microsites for floristic development. For instance, many ericaceous shrubs tend to develop on the top of

Sphagnum hummocks rather than in hollows. Likewise, certain species of *Sphagnum* occupy higher, drier positions on hummocks than others (Vitt et al., 1975, Crum, 1992). In addition to the vertical microsites offered by hummocks, the variation from the center of the peatland to the periphery also provides interesting gradients. Many *Sphagnum*-dominated peatlands are encircled by a moat (or lagg) more reminiscent of swamp or marsh vegetation. Chemistry, hydrology, and vegetation changes are apparent along this interior to lagg gradient. **Nutrient gradients** have also been a subject of interest and debate in peatlands. Currently there is much disagreement as to the existence and importance of nutrient gradients. This ranges from the view that there are pronounced nutrient gradients along the bog-to-fen continuum that are of major importance in classifying peatlands (Wheeler and Proctor 2000), to those finding less consistent variation and attaching little important to nutrient gradients (Vitt and Chee 1990). It may well be that regional differences affect the importance of this gradient in differentiating peatland types. The **sun to shade gradient** is important for considering aspects of *Sphagnum* ecology (see Chapter 4). Many species of *Sphagnum* are intolerant of shade (Crum 1992), and the growth of shrubs and trees in peatlands can be an important variable affecting shade, both between peatland types and within individual peatlands. **Seasonal variation** can be important for some parameters, particularly hydrological and physical ones. However Vitt et al. (1995) found little seasonal variation in surface water chemistry parameters in *Sphagnum*-dominated peatlands.

1.6 Identification of *Sphagnum*-dominated Peatlands for this Report

In addition to information available in King County, contacts were made in the spring of 2000 with other counties, cities, state governments, environmental organizations and consultants to identify the locations of *Sphagnum*-dominated peatlands and sources of biological, physical or chemical information regarding these peatlands. In all, about 250 *Sphagnum*-dominated peatlands were identified in the low-elevation areas of western Washington (areas less than 600 m or 2,000 feet msl). Sources of information include field-verified wetland inventories, wetland delineations, records in the Washington Natural Heritage Program database having the descriptors "*Sphagnum* and *Ledum,*" and peatlands identified as *Sphagnum* bogs in Rigg, Peat Resources of Washington (1958). Since many of the *Sphagnum*-dominated peatlands described by Rigg have either been mined or are no longer dominated by *Sphagnum* mosses, this total includes historic *Sphagnum*-dominated peatlands in addition to existing ones. Additional *Sphagnum*-dominated peatlands that were not identified for this report undoubtedly exist.

The physical, biological, and chemical information compiled for western Washington *Sphagnum*-dominated peatlands varies considerably in detail and completeness. Data were compiled from multiple sources, each with a different purpose and level of information. This makes it difficult to draw strong conclusions from the information. General trends, however, can be determined, although the number of specific observations is small. The reliability of the data and observations therefore varies. Appendix B identifies all *Sphagnum*-dominated peatlands for western Washington from contacts made in spring 2000, categorized by county. An X preceding the peatland name indicates the *Sphagnum* resource is known to be extirpated. In this case the system may currently be a non-*Sphagnum*-dominated peatland, a non-peat accumulating wetland, or it may be filled.

1.7 Area Covered by this Report

This report compiles information on the low-elevation peatlands of western Washington. Lowland western Washington refers to that region lying westward of about 600 meters (2,000 feet) in the Cascade mountain range to the Pacific Ocean, north to the Canadian border and south to the Columbia River, the border with the state of Oregon. The higher elevation areas of the Cascades and Olympics were excluded from this report because the peatlands of this area are of a distinctly different character, having extremely short growing seasons, a distinct alpine-influenced flora, and many areas that did not experience continental glaciation. The Olympic Mountains form an island within this region. The area of the Olympic Mountains above 600 meters (2,000 feet) is likewise not covered by this report. However, some information from higher elevations and from the neighboring regions of western Oregon and British Columbia is occasionally offered for the sake of comparison.

1.8 Chapter One References

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